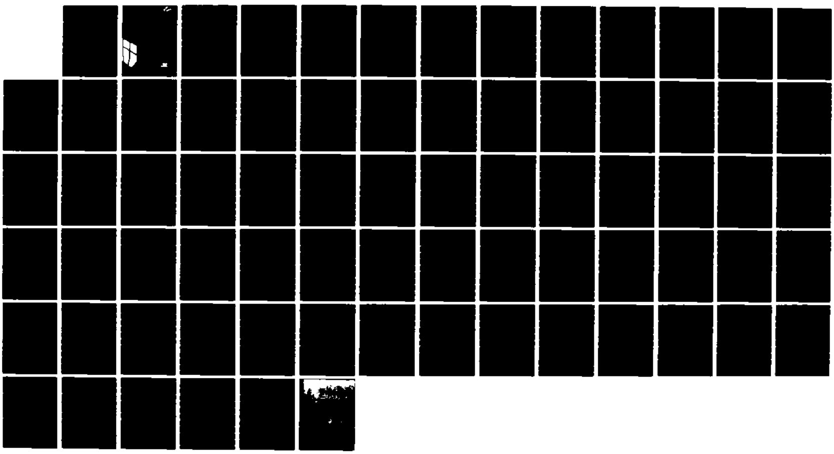
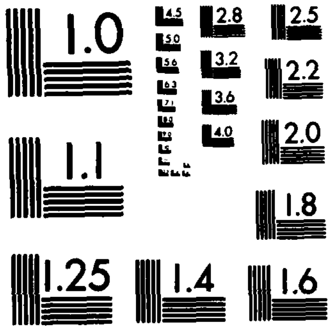
AD-A132 527 ANALYSIS OF FACILITIES' ENERGY USE PATTERNS(U) 1/1
CONSTRUCTION ENGINEERING RESEARCH LAB (ARMY) CHAMPAIGN
IL B J SLIWINSKI ET AL. AUG 83 CERL-TR-E-186

UNCLASSIFIED F/G 5/3 NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

AD-A132527

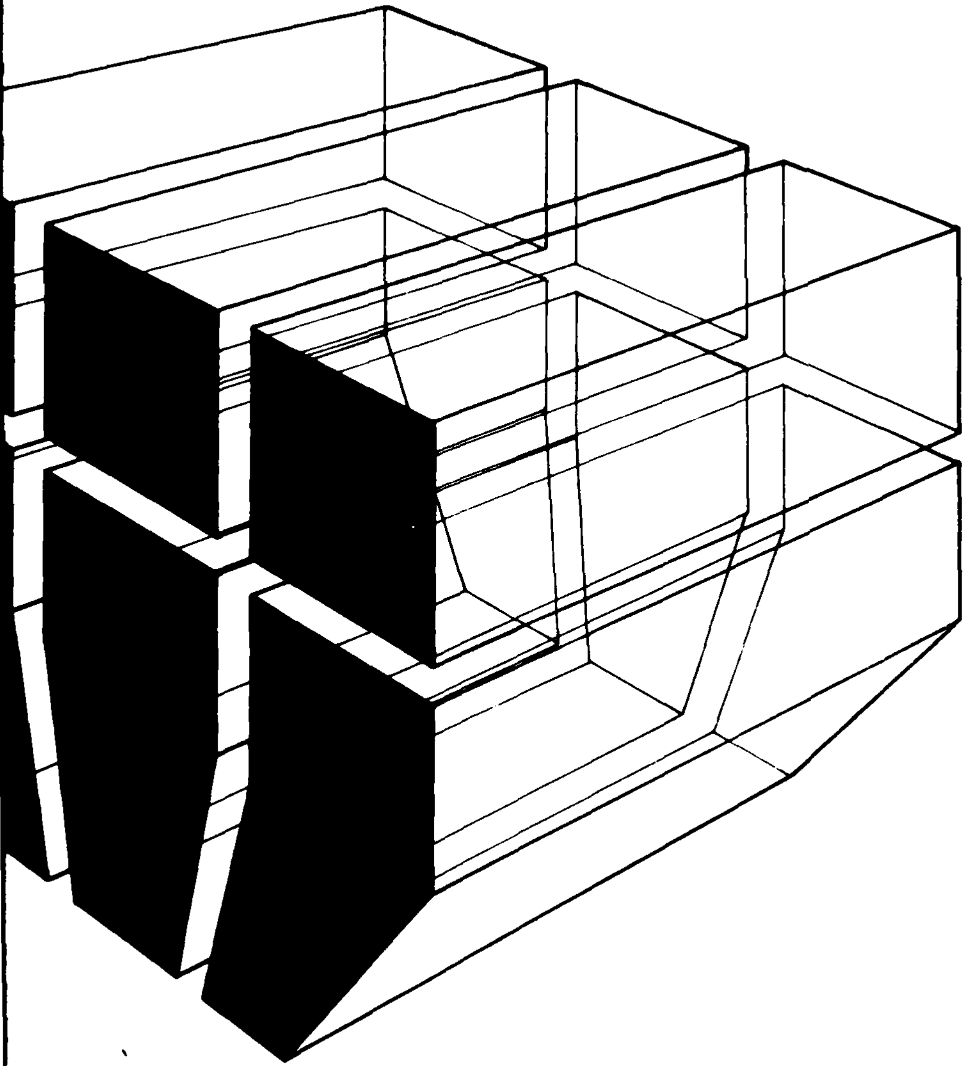
AD-A132527

construction
engineering
research
laboratory

United States Army
Corps of Engineers
...Serving the Army
...Serving the Nation

TECHNICAL REPORT E-186
August 1983
Handbook of Facility Energy Use Patterns

ANALYSIS OF FACILITIES' ENERGY USE PATTERNS



by
Ben J. Sliwinski
Elizabeth Elischer

CERL

Approved for public release; distribution unlimited.

83 09 15 006

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER CERL-TR-E-186	2. GOVT ACCESSION NO. AD-A132 527	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) ANALYSIS OF FACILITIES' ENERGY USE PATTERNS		5. TYPE OF REPORT & PERIOD COVERED FINAL 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Ben J. Sliwinski Elizabeth Elischer		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 4A762781AT45-B-003
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE August 1983 13. NUMBER OF PAGES 68
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Copies are available from the National Technical Information Service
Springfield, VA 22161

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

buildings
energy consumption
linear regression analysis
time series analysis

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report describes the development of methods for estimating building energy consumption based on analysis of weather and energy use data. Equations are presented for estimating Army facilities' energy consumption based on daily heating and cooling degree days. The results of the regression analysis indicated that these equations can be used to estimate energy consumption for aggregates of 10 or more buildings. The equations are useful for all types of Army buildings. Time series analysis of facilities' electrical energy consumption is also described. This analysis

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

BLOCK 20. (Continued)

provides the Facilities Engineer with a basis for estimating daily electric energy consumption and a methodology for using accurate short-term electrical metering to estimate daily average electrical consumption.

FOREWORD

This work was performed for the Assistant Chief of Engineers under Project 4A762781AT45, "Energy and Energy Conservation"; Technical Area B, "Installation Energy Conservation Strategy"; Work Unit 003, "Handbook of Facility Energy Use Patterns." The work was performed by the Energy Systems Division (ES), U. S. Army Construction Engineering Research Laboratory (CERL). Mr. B. Wasserman (DAEN-ZCF-U) was the Technical Monitor.

A portion of the regression analysis was performed by TPI, Inc., Beltsville, MD. Appreciation is expressed to Mr. Robert Neathammer and Mr. Michael O'Connor of CERL for their assistance in the time series analysis portion of the work. Mr. R. G. Donaghy is Chief of CERL-ES.

COL Louis J. Circeo is Commander and Director of CERL, and Dr. L. R. Shaffer is Technical Director.

CONTENTS

TABLES

FIGURES

FIGURES (Cont'd)

ANALYSIS OF FACILITIES' ENERGY USE PATTERNS

1 INTRODUCTION

Background

Eighty-four percent of the energy that the Army consumes annually is used to operate its installations. The cost of this energy is $1 billion per year. To manage the use of energy resources on Army installations effectively, Facility and District Engineers need improved ways to estimate the energy consumption of buildings. Computer programs, which provide very accurate estimates, often require large amounts of input data and much time to set up. What is often needed is a quick, inexpensive way to get a reasonable estimate of the energy consumption of various Army buildings. Such a method also should allow the engineer to assess potential energy conservation techniques.

The Army's development of building energy consumption estimation methods began in 1975 with the Fixed Facilities Energy Consumption Investigation (FFECI), a joint effort of the U. S. Army Construction Engineering Research Laboratory (CERL) and the Facilities Engineering Support Agency (FESA). The FFECI data and previous analyses are described in CERL Reports E-127, E-120, and E-143.[1]

Objective

The objective of this study is to develop methods of estimating building energy consumption that are based on a comprehensive analysis of available weather and energy-use data. The methods can be used by Directorate of Engineering and Housing (DEH), District, and Major Army Command (MACOM) engineers in analyzing, planning, and budgeting of Army installation energy use.

[1] L. Windingland, et al., *Fixed Facilities Energy Consumption Investigation Data Users Manual*, Technical Report E-127/ ADA052708 (U. S. Army Construction Engineering Research Laboratory [CERL], 1978); L. Windingland and B. Sliwinski, *Fixed Facilities Energy Consumption Investigation—Initial Energy Data*, Interim Report E-120/ADA051074 (CERL, 1978); B. Sliwinski, et al., *Fixed Facilities Energy Consumption Investigation—Data Analysis*, Interim Report E-143/ ADA066513 (CERL, 1979).

Approach

Scatterplots and linear regression were used to analyze FFECI data. The analysis was used to determine the effects of daily heating and cooling degree days and other weather parameters on building energy consumption.

A time series analysis of FFECI electrical consumption data was done to characterize a typical daily energy consumption profile, to examine the feasibility of developing predictive algorithms suitable for use by Energy Management and Control Systems (EMCS), and to develop guidelines for short-term electrical energy monitoring efforts.

Mode of Technology Transfer

It is recommended that the information in this report be disseminated by Engineering Technical Notes on the following subjects:

1. Estimating Army facilities energy consumption

2. Guidelines for short-term electrical metering based on time series analysis.

2 REGRESSION ANALYSIS

The work described in this chapter is based on analyses by CERL[2] and work by TPI, Inc., Beltsville, MD.

Hourly energy consumption data taken between 1976 and 1979 were analyzed for 70 buildings at Fort Carson, CO, Fort Hood, TX, and Fort Belvoir, VA. These data consisted of electricity and gas consumption information for family and troop housing, and for administrative, community, medical, maintenance, and storage facilities.* Regression analysis was used to determine the effects of weather parameters on energy consumption. Scatterplots of the data were produced to characterize, qualitatively, the patterns of energy consumption observed.

[2] L. Windingland, et al.; L. Windingland and B. Sliwinski; B. Sliwinski, et. al.

*Throughout this report, the building numbers are FFECI data point identifiers and *not* post building numbers, unless otherwise indicated.

Data Processing

One of the biggest problems of any data analysis effort is the production of a clean, usable data set from field data which may have a variety of problems. Therefore, the first step in analyzing the FFECI data was to generate a clean data set. This was done primarily by eliminating suspect or "bad" data. No attempts were made to correct or recover data.

There are several types of bad data. The easiest type to identify has large blocks of data where nothing but zeros are entered. These can be eliminated easily during the computer data analysis. A harder problem to eliminate is the presence of sporadic small signals intermingled with the zeros, which give the appearance of nonzero readings. Since small readings may legitimately occur for certain buildings during certain times of the year, one cannot arbitrarily eliminate all data below a certain value. The days at the beginning and end of a zero block may also have substantial error. Zeros may also appear in readings taken for several hours in a day, but not cause that day's total to be zero.

There are also blocks of data which have significant daily values because of sporadic noise or bad sensors. These blocks of data can be recognized by pattern, but not necessarily by daily magnitude. There are also a limited number of data points which are much too large, because of either capacity limitations or the time of year.

Using only the computer to eliminate data which fall into these categories would have required a major program development effort and still not have provided certainty. Therefore, a combination of computer and visual techniques was used to identify anomalous data. The hourly and daily data were printed out for all buildings in the study. The output was then scanned visually to identify data to be removed. Most bad data were identified, although it was impossible to note every piece with just visual scans.

After the bad data were eliminated, scatterplots were generated for each building. They helped provide a better understanding of the correlations and also allowed additional outliers to be identified. Additional sections of data were then eliminated using these scatterplots to seek bad data.

Based on the information available for analy-, further removal of data was not justified. Althou correlations were poor in many cases, it was felt that this was a result of a building's operations and characteristics rather than data anomalies.

Weather Data

Files of weather data were produced for Forts Carson, Hood, and Belvoir as part of the data processing and as a preliminary step to further analysis. The weather data sites used were, respectively, Colorado Springs, CO, Waco, TX, and Washington, DC. TPI obtained the weather data[3] from the Department of Commerce's National Oceanic and Atmospheric Administration (NOAA). The data were in two slightly different formats. Colorado Springs and Waco data were in NOAA format CD144, and the Washington, DC, data tapes were from the SOLMET series. The SOLMET tapes contain directly measured total horizontal insolation, which the CD144 tapes lack; the CD144 tapes contain wet-bulb and relative humidity data, while the SOLMET tapes provide dew point information. The SOLMET tapes also provide hourly weather data, and the CD144 tapes provide data for 3-hour periods. The SOLMET tapes are in SI units, while the CD144 tapes are in English units.

TPI developed two programs to produce daily weather statistics from the NOAA tapes: WETHER and SOLMET. The WETHER program for the CD144 tapes produces the following daily weather statistics: maximum, minimum, and average dry bulb; maximum, minimum, and average wet bulb; average relative humidity; average wind speed; average wind direction (weighted by wind speed); wind dominance; and estimated global insolation. The wind dominance statistic indicates, in a range of 0 to 100 percent, the dominance of a particular average wind direction for a specific day. The SOLMET program provides roughly the same information, except that the wet-bulb and relative humidity statistics are replaced by average dew point.

The estimated global radiation was derived from the opaque cloud cover measurement on the NOAA tapes using the algorithm developed by Machta and Cotton of NOAA's Air Research Laboratory. Machta and Cotton developed two equations: one relates clear sky solar radiation to solar azimuth angle, and the other calculates a modifier for clear sky solar radiation based on the percent opaque

---

[3] ription of *Weather Data Analysis*, TPI/SR 81-04 (TPI, Beltsville, MD., May 5, 1981).

cloud cover statistic. Regressions were performed for 26 weather stations throughout the continental United States for which sufficient solar radiation data were available. Regression coefficients for the clear sky equation were obtained separately for morning and afternoon values, and the constant term differs for each month. Three subroutines were written to implement this algorithm—one for each of the three National Weather Service Stations.

After data processing and the production of weather data files, an analysis was performed to determine the effects of various weather parameters on the buildings' energy consumption. Earlier CERL studies[4] had examined aspects of the dependence of energy consumption on heating degree days (HDD) and cooling degree days (CDD). The scatter which appeared in some of these correlations led to a need to determine if other weather parameters might improve the correlations.

Description of Regression Analysis

The multiple regression procedure was the principal statistical technique selected for the analysis. This technique allows the researcher to analyze, quantitatively, the relationship between a "dependent" variable (to be predicted or explained) and a set of "independent" variables. The multiple regression technique produces an equation relating the dependent variable to the set of independent variables. It also provides statistics which quantify the explanatory powe· ·f the regression equation, the expected errors of this equation, and the statistical significance of each independent variable.

Several variables are often measured for a given phenomenon ("event"). To use regression techniques, these variables must be partitioned between the dependent variable and the independent variables. This partition can be made by a number of criteria. Where physical causality is well established, the choice of the partition is usually clear. Since the basic heat transfer mechanisms of building energy consumption are well understood, the selection of these variables is relatively straightforward for a single building. The dependent variables are those to be predicted—daily electrical and gas consumption for each building.

The selection of independent variables presents a slight problem. The obvious variables are temperature, wind velocity, insolation, and perhaps wind direction and relative humidity. However, other "variables" also effect the daily energy consumption of buildings. These variables are primarily related to building occupancy. For example, if a family is away for a weekend, one would expect the infiltration rate to be lower, since outside doors will not be opened; hence, energy consumption will be lower. Unfortunately, such variables are very hard to quantify, with the possible exception of weekend/weekday differences for administration buildings. Examining the effects of these variables is only rarely practical. They are not accounted for in the set of independent variables, however, and this reduces the explanatory power of the regression equations. Data on these variables were not available for this study.

Another problem with the independent variables arises from their causal interrelationships. For example, insolation and temperature are closely linked variables on a daily level. Solar heating as a causal mechanism in diurnal temperature fluctuations is well known to meteorologists. However, this causal relationship provides both direct and indirect paths by which insolation can affect energy consumption in buildings. For example, direct solar gain can be a major component in cooling loads. The solar radiation increases air temperatures, which results in greater conduction and infiltration cooling loads. If both insolation and temperature are included in the independent variable list, there can be problems in separating the direct and indirect effects of the insolation variable.

Analytically, there are two approaches for explaining the regression technique. The first one derives the regression procedure from a minimum sum of squared errors approach. The regression technique is defined as the mathematical procedure which selects the linear combination of the independent variables that minimizes the sum of the squared distances between the points of the dependent variable and the line in hyperspace defined by the linear combination of the independent variables. The minimum sum-of-squares definition of multiple regression requires no assumption about the statistical distribution of the dependent variable. However, this definition does not allow a statistical analysis of significance and predictive error.

The second approach—the maximum likelihood definition—overcomes this problem. This approach begins with a few not-too-restrictive assumptions.

[4] L. Windingland, et al.; L. Windingland and B. Sliwinski; B. Sliwinski, et al.

First, it assumes that the following physical model determines the relationship between the dependent and independent variables:

$$Y_i = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_m X_m + \epsilon_i \quad \text{[Eq 1]}$$

where Y_i is the dependent variable, the X_i's are the independent variables, the β_i's are the linear coefficients of the physical relationship, and ϵ_j is an error random variable.

In addition, it is assumed that ϵ is normally distributed with mean zero, and that ϵ_j and ϵ_k are uncorrelated. Based on these assumptions, the multiple regression technique selects a set of coefficients, $B_0, \ldots, B_m$, based on a sample of points, These "B" coefficients have the maximum likelihood (greatest probability) of equaling the true "β" coefficients, based on the given sample of points.

Three statistics are used to describe the resulting regression equation. These statistics quantify goodness-of-fit, statistical significance, and predictive accuracy.

The most commonly known regression statistic is the "R-squared" goodness-of-fit. This statistic represents the percentage of the variance of the dependent variable which is explained by the variance of the independent variables. Thus, an R-squared value of 0.87 indicates that 87 percent of the variance in, for example, gas consumption is explained by the combined variance of, for example, heating degree days and insolation. An R-squared value of 87 percent indicates a fairly good correlation, while an R-squared value of, say, 17 percent indicates a poor correlation.

The statistical significance of the regression is determined by a number of F-tests. The F-statistic is basically the ratio of sums-of-squares divided by their degrees of freedom. This statistic allows for a hypothesis test on the significance of the entire regression equation and on the significance of individual coefficients. For the overall significance test, the null hypothesis is that all the regression coefficients are zero, which implies that no relationship exists between the dependent variable and any independent variable. Given the null hypothesis, the overall F-statistic follows the F distribution. If a 99 percent significance level is chosen for the F-test, then the null hypothesis would be rejected if the F-statistic fell within the upper 1 percent tail of the F distribution. In other words, if the F-statistic fell within the tail, there would be a probability of .01 or less that this value of the F-statistic would occur by chance. Thus, it is reasonable to assume that a statistically significant relationship does exist.

The second type of F-test determines the significance of individual regression coefficients. The F-statistic in this test is formed by examining the additional variance explained by adding the variable in question after all other regression coefficients have already been taken into account. This test determines the statistical significance of the variance explained by the variance remaining in a given independent variable after all the covariance with other independent variables has been removed.

The final statistic is the standard error of the regression coefficient (S.E. of B). This statistic approximates a normal distribution when the number of cases is above 200. Below 200 points, this statistic approximates a Student's-t distribution. The S.E. of B allows confidence intervals to be calculated for the regression coefficients and for the resulting predicted values of the dependent variable.

The specific regression procedure used by the SPSS computer routines employed in this analysis is termed the "forward selection" procedure. This procedure selects the independent variables, one by one, on the basis of the F-statistic on the individual variables. The variable selected is entered into the regression equation at each step and the F-statistics are computed for the remaining variables not in the equation. The forward selection procedure allows the researcher to select a level of statistical significance and ignore the equations which include variables below that level.

Regression Results

The regression performed for this study examined the effects of ambient temperature (as HDD and CDD), solar radiation, wind speed, and relative humidity on gas and electric energy consumption. Humidity was not found to be a significant variable in any of the regressions performed. However, solar radiation and wind speed were slightly significant in several regressions. Generally, it was found that HDD and CDD are the most significant weather variables relating to energy consumption.

Energy consumption can vary widely among individual buildings. Therefore, the regression analysis results presented in the sections below should be used to estimate consumption for aggregates of buildings (i.e., 10 or more).

Family Housing

Family housing is divided into four categories: single-family, duplex, fourplex, and eightplex. Table 1 shows the regression results (slope and constant). Key building parameters are also included in the table.

The relationship between the constant term in the regression analysis and various building parameters was obtained by comparing the energy consumed per square foot of floor with the energy consumed per family. Table 2 shows the constant energy consumed per square foot of floor area columnated by the number of families in the building. Figure 1 illustrates the data both in terms of consumption (cubic feet of gas per family) versus the number of families and in terms of average consumption per family versus number of families. The data have considerable scatter when individual building data are used, but the average consumption per family shows a clear declining consumption rate. The constant term can also be analyzed on a per-square-foot basis rather than per family. Table 1 shows the constant term multiplied by 1000 Btus per cubic foot of gas divided by the floor area. The distribution of these data has less scatter than that of the per-family basis, as shown by the mean and σ_x, the standard deviations (excluding Buildings 319 and 322).

$$\text{Per Family:} \quad \text{Mean} = 183 \text{ cu ft/day}, \quad \sigma_x = 58$$

$$\text{Per Square Foot:} \quad \text{Mean} = 122 \text{ Btu/sq ft/day}, \quad \sigma_x = 22.5$$

The slope term is not nearly so well-behaved as the constant term. Table 1 provides the slope coefficient of each building in terms of Btu/sq ft/HDD_d where HDD_d are daily heating degree days.

The electricity consumption in family housing varied considerably because some units did not have air conditioners. For houses with no air conditioning (primarily at Fort Carson), the insolation term is the most statistically significant variable in the regressions. Buildings 110, 115, and 122 have insolation variable coefficients which are statistically significant, but only marginally so. This slight correlation is negative and probably reflects the increased lighting and applicance use during shorter days of the year.

Buildings without air conditioning showed no correlation with CDD. For these buildings, a value of 01659 kWh/sq ft/day was obtained from regression analysis of daily electric use.

Table 1

Family Housing Regression Results for Daily Energy Consumption (Gas)

(Assume 1000 Btu/C.F.)

Building Type	Building Number	Levels	[illegible] (Btu/ft² HDD)	[illegible]	[illegible]	Wall Area	Window Area	UA (Btu/DD)
Single Family	110	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	115	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	325	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	329	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Duplex	116	2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	204	2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	205	2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	210	2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	211	2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	22920
	213	2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	214	2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	24984
	319	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	15408
	320	1	[illegible]	[illegible]	[illegible]	[illegible]	188	16728
	322	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	28440
	324	1	[illegible]	[illegible]	[illegible]	1196	188	13584
	371	1	103	4.4	2802	2394	[illegible]	27864
	372	1	106	[illegible]	2720	2244	338	13056
Fourplex	122	1	104	14.4	4900	3180	556	29664
Eightplex	327	2	74	[illegible]	[illegible]	9781	1469	103800

Table 2
Regression Constant for Family Housing Versus Number of Families
(Cu Ft Gas/Day)

No. of Families	1	2		4		8	
		Total	Per Family	Total	Per Family	Total	Per Family
	289	188	94	509	127	935	117
	197	386	193				
	197	407	203				
	319	378	189				
	147	422	211				
	288	304	152				
		438	219				
		337	168				
		289	145				
Average	239.5	350	175	509	127	935	117

Note: Buildings 319 and 322 have not been included in these data.

The use of electricity for air conditioning showed strong correlations in the Fort Hood and Fort Belvoir homes. The figures in Table 3 show the electric slope term on a per-square-foot of floor space basis. Notice that although the consumption for individual buildings varies greatly, the averages for the categories are quite close. One may therefore conclude that in hot climates (Belvoir and Hood), the air-conditioning consumption rate for family housing will be about .00176 kWh/sq ft/CDD.

The results of the regression analysis done by TPI in 1980–1981 on family housing are in near agreement with those obtained by CERL.[5] The TPI results indicate a smaller heating slope term and a larger cooling slope term. The constant terms in each study agree very well. Equations 2, 3, and 4 are obtained by averaging the slope constants obtained in the studies.

Heating:

$$E_h = 113.5 + 16.5 \times HDD_d^{*} \text{ (Btu/sq ft/day)} \quad \text{[Eq 2]}$$

Electricity:

For air-conditioned buildings:

$$E_c = .01359 + .00172 \times CDD_d \text{ (kWh/sq ft/day)} \quad \text{[Eq 3]}$$

For non-air-conditioned buildings:

$$E_c = .01659 \text{ (kWh/sq ft/day)} \quad \text{[Eq 4]}$$

These equations should be used to estimate the energy consumption of aggregates of buildings (i.e., 10 or more). (It is evident from TPI's and CERL's work that consumption varies widely among individual buildings. (See Table 1 and CERL TR E-143).

Troop Housing

The heating results presented below for troop housing are based on analyses performed by CERL.[6]

Analysis of heating energy use data for barracks showed poor correlation with HDD when no groupings were made with respect to the barracks' year of construction. However, when the year of construction was considered, there were good correlations. The barracks were divided into three age categories: barracks built before 1966, including World War II types, which are designated as "old"; barracks built after 1966 (except for the modern Army modular type), which are designated as "new, nonmodular"; and barracks of the modern Army modular type, which are designated as "modular." The equation for daily heating energy use by old barracks was:

$$E_h = 130.5 + 15.99 \times HDD_d \text{ (Btu/sq ft/day)} \quad \text{[Eq 5]}$$

[5]L. Windingland, et al.; L. Windingland and B. Sliwinski; B. Sliwinski, et al.

*HDD_d = daily heating degree days.

[6]L. Windingland, et al.; L. Windingland and B. Sliwinski; B. Sliwinski, et al.

Table 3
Electric Slope Term (Family Housing)
(kWh/sq ft/CDD)

Single-Family	Duplex	Fourplex	Eightplex
.00125	.00252	--	.00171
←	← .00217 ←	.00139	
.00151	.00136		
	.00208		
	.00177		
	.00275		
	.00243		
	.00182		
	.00138		
	.00079		
← Avg./Bldg. ←	.00164 ←	.00183 ←	.00171

For new, nonmodular barracks, the equation was:

$$E_h = 81.91 + 7.4 \times HDD_d \text{ (Btu/sq ft/day)} \quad \text{[Eq 6]}$$

As shown in these equations, the new, nonmodular barracks use about half the energy per HDD_d as the old barracks.

When data from modular barracks were included in the regression analysis with data from new, nonmodular barracks, poor results were obtained. However, when these data were grouped separately, the results were good. The heating energy for modular barracks is supplied by hot water from a central plant. The equation for daily heating energy use for the new modular barracks was:

$$E_h = 295.9 + 34.32 \times HDD_d \text{ (Btu/sq ft/day)} \quad \text{[Eq 7]}$$

This indicates that the modular barracks in this sample use about four to five times more heating energy per HDD than the new, nonmodular barracks.

The results for barracks electrical consumption are based on analysis by TPI and CERL.[7] Analysis of electric energy use data taken from new, nonmodular barracks with air conditioning showed reasonable correlation with CDD. Some of the scatter in the data results because some of the buildings are cooled by central chillers which use water-cooled condensers; this increases the effect of dew-point temperature on energy consumption. The following equation, obtained for daily electric energy use for barracks with air conditioning, was developed by averaging the slope and constant terms of the TPI and CERL studies:

$$E_c = .01566 + .00149 \times CDD_d \text{ (kWh/sq ft/day)} \quad \text{[Eq 8]}$$

For barracks without air conditioning, the value obtained from the regression analysis for daily electric use was .0152 kWh/sq ft. This does not include old barracks built between 1941 and 1945; for these buildings, the regression analysis provided a value of .0065 kWh/sq ft.

Administration/Training Facilities

The results for administrative/training facilities are based on analyses performed by CERL.[8]

Analysis of heating energy use data for administration/training buildings showed good correlation with HDD. Some of the scatter in the data results from variation in building type, site, and use. For example, some of the buildings were administration/classroom buildings, and others were administration/supply. The supply buildings, in particular, were likely to have large air infiltration rates at certain times. The equation obtained for daily heating energy use for administration/training buildings was:

$$E_h = 76.71 + 18.97 \times HDD_d \text{ (Btu/sq ft/day)} \quad \text{[Eq 9]}$$

[7] B. Sliwinski, et al.

[8] B. Sliwinski, et al.

Data for electric energy use did not correlate well with CDD. Averages were calculated for the months of May through September and October through April. The average daily electric energy use for May through September was:

$$E_e = .0512 \text{ (kWh/sq ft/day)} \quad \text{[Eq 10]}$$

For October through April, the average daily electrical energy use was $E_e = .0215$ kWh/sq ft/day.

Dining Facilities

The analyses done by TPI and by CERL both indicate very little correlation between dining facility energy consumption and HDD or CDD. Table 4 indicates the heating (including cooking and hot water) energy consumption for the dining facilities analyzed by TPI. The average consumption from Table 4 is:

$$E_h = 241.9 \text{ Btu/sq ft/day}$$

Table 5 gives electrical energy consumption figures for dining facilities. Based on the data in Table 5, the average daily electrical energy consumption is:

$$E_e = .04701 \text{ kWh/sq ft/day}$$

Medical/Dental Facilities

The results for medical/dental facilities are based on the analysis performed by CERL.[9] Analysis of heating energy data for medical/dental buildings showed a fair correlation with HDD days. The sample consisted of dispensaries and dental clinics; no hospitals were included. The equation for daily heating energy for medical/dental buildings was:

$$E_h = 254.4 + 24.31 \times HDD_d \text{ (Btu/sq ft/day)} \quad \text{[Eq 11]}$$

[9] B. Sliwinski, et al.

Table 4
Heating Energy Consumed in Dining Facilities

Bldg.	Btu/Day	Sq Ft	Btu/Sq Ft/Day
118	615000	19089	32.21
130	5445000	13270	410.32
131	702000	13270	52.90
145	8164000	26732	305.40
333	2879000	15695	183.43
353	10907000	23345	467.20

Table 5
Dining Facilities Electrical Energy Consumption

Bldg.	Floor Area	kWh/Day	kWh/Sq Ft/Day
118	19089	1254	.06569
130	13270	395	.02977
131	13270	331	.02494
145	26732	355	.01328
353	23345	2366	.10135

Data for electrical use did not correlate well with CDD. This was primarily due to differences in energy use among buildings. The daily average energy use for May through September was:

$$E_e = .0557 \text{ kWh/sq ft/day}$$

The value for October through April was:

$$E_e = .0353 \text{ kWh/sq ft/day}$$

Production/Maintenance Facilities

The results for production/maintenance facilities are based on analyses performed by CERL and TPI.[10]

Analysis of heating energy use data for production/maintenance facilities* showed a large degree of scatter. This was expected because these facilities have large, high bay doors and can have very large air infiltration rates during certain maintenance activities. Large amounts of heat are also generated by welding torches and other equipment. The equation for daily heating energy consumption for production/maintenance facilities was:

$$E_h = 91.46 + 31.38 \times HDD_d \text{ (Btu/sq ft/day)}$$

The data for electricai energy consumption showed no correlation with CDD. The value obtained for daily average electrical energy use was:

$$E_e = .0264 \text{ kWh/sq ft/day} \quad \text{[Eq 12]}$$

Community Facilities

Data from community facilities was difficult to analyze because of the diversity of buildings within

[10] B. Sliwinski, et al.

*Production facilities did not include major process-type production buildings such as DARCOM ammunition plants, but only those with production activities such as light machining, assembly, and other activities associated with installation maintenance.

this category. However, the data for the gymnasium and fieldhouse did correlate well with HDD.

The equation for daily heating energy use for fieldhouses and gymnasiums was:

$$E_h = 73.69 + 32.4 \times HDD_d \text{ (Btu/sq ft/day)} \quad \text{[Eq 13]}$$

The equation obtained for one commissary which did correlate with HDD was:

$$E_h = 147 + 14.17 \times HDD_d \text{ (Btu/sq ft/day)} \quad \text{[Eq 14]}$$

None of the electrical energy consumption data correlated with CDD. Table 6 gives the consumption averages for all buildings analyzed.

Storage Facilities

The results presented for storage facilities are based on the CERL analysis.[11]

Analysis of heating energy data for storage facilities correlated well with HDD. The equation obtained for heating energy use for storage buildings was:

$$E_h = 35.7 + 36.1 \times HDD_d \text{ (Btu/sq ft/day)} \quad \text{[Eq 15]}$$

[11] B. Sliwinski, et al.

Table 6
Electrical Consumption Averages
for Community Facilities

Building	Type	Consumption (kWh/sq ft/day)
143	Commissary	.09720
149	Commissary Annex	.2130
220	Commissary	.1495
227	Swimming Pool	.0191
239	Theater	.0319
336	Branch PX	.0610
354	Commissary	.0816
364	Gymnasium	.0139
375	Field House	.0354
362	Community Center (Summer)	.0709
362	Community Center (Winter)	.0446
376	Main PX (Summer)	.0345
376	Main PX (Winter)	.0202

None of the storage facilities in this sample was air-conditioned.

The value for daily average electric energy use was:

$$E_d = 0.0141 \text{ kWh/sq ft/day}$$

Central Plant Data Analysis

Under FFECI, energy consumption data, in the form of circular charts and daily logs, were gathered for the High Temperature Hot Water Plant (Building 1860) at Fort Carson, CO. This plant provides high-temperature hot water in the winter for heating and hot water to an absorption chiller plant in the summer for cooling. The plant output averages 450 million Btu/day in the summer and 1000 million Btu/day in the winter.

A linear regression was performed on the central plant data to determine the relationship between the plant load and heating and cooling degree days. The results indicated a poor correlation between plant load and CDD but a good correlation with HDD for January, February, and March of 1978. Figures 2, 3, and 4 illustrate these relationships.

Results of Scatterplots

Scatterplots were produced to develop regression equations relating energy consumption to weather parameters for each type of building. The scatterplots consisted of energy consumption in terms of daily kilowatt hours or cubic feet of natural gas plotted as a function of the average daily dry-bulb temperature (DBAVG). The scatterplots are useful in a qualitative sense for characterizing the behavior of the various buildings' energy consumption.

The most pronounced pattern of consumption is the "check mark" pattern of electrical energy consumption. Figures 5, 6, and 7 illustrate this pattern of energy consumption for an administration/training facility at Fort Hood, a dispensary at Fort Carson, and a family housing duplex at Fort Belvoir. It is significant that this consumption pattern is the same for different types of buildings; i.e., it is typical of a building whose air-conditioning demand is strongly correlated with outside temperature. Most buildings exhibiting this type of pattern were family housing. The "knee" of the check mark occurs at the cooling balance point for a particular building. This pattern of energy consumption indicates a building that would be a candidate for energy reduction in the summer through a higher set-point temperature. If a building with a "check mark" pattern of energy consumption has a sharp slope for temperatures below 65° F (i.e., the heating season), occupants may be using electric space heaters, or some other seasonal temperature-related electrical demand may exist; such a building may be a candidate for lighting reduction.

The next clear-cut pattern of consumption shown in the scattergrams is a simple straight-line relationship between daily gas consumption and daily average dry-bulb temperature. This pattern is not unexpected, and is one of several which occurred. Figures 8, 9, and 10 are examples, respectively, of a straight-line relationship for the gas consumption of an administration/training building, a dispensary, and a post headquarters. These scattergrams indicate buildings whose heating energy consumption is closely related to the outside temperature. Although the buildings maintain similar temperatures, there are obvious differences between the three scattergrams. The differences may be used as a guide to determine energy conservation measures, at least qualitatively. For example, the dispensary data indicate that the building may be fairly tight, or at least that effects of outside air infiltration are very repeatable. The broadening of the scatter around 10 cu ft per day is due to water heating or other small gas consumers not directly related to outside temperature.

Since the dispensary shows a controlled pattern of energy consumption, options for energy conservation might include insulation, reduction in HVAC outside air, and reduced set-point temperature. The occupants' behavior does not appear to have a large impact on the building's energy consumption.

The scattergram for the administration/training building indicates that the maximum energy consumption per day is governed by the building envelope. This is indicated by the sharp edge on the top right-hand side of the data, as opposed to the scatter on the lower left-hand side. Since the scatter occurs on the left side, it indicates that there are often conditions, such as solar radiation and internal heat gains, which cause the building to use less energy than would be expected from consideration of the envelope alone. Conservation options for this building would be similar to those of the dispensary, except that a study of occupant behavior may be indicated, since the occupants may sometimes have an effect on reducing consumption.

The scattergram for the post headquarters indicates that the general relationship between energy consumption and outside temperature is similar to that of the other buildings; however, there is much stronger occupant effect, as indicated by the large degree of scatter in the data. Thus, the first step in reducing energy consumption for this building would be to study its occupant behavior.

A third clear-cut pattern in the scattergrams was the "split" consumption pattern. This occurred primarily for electrical consumption data for a warehouse and an administration building (see Figures 11 and 12). Split data occurred occasionally for gas consumption data for a BOQ (see Figure 13). The split electrical consumption data represent the difference between weekday and weekend consumption and indicate the difference between weekday and weekend consumption. These data are positive indicators that occupants are turning off equipment when they leave the building.

The split gas consumption data for the BOQ is probably not caused by weekend, weekday variations because occupancy probably does not vary significantly throughout the week. It is more likely that the split is caused by an unoccupied period such as during field maneuvers.

In either case, the split data can indicate the maximum energy reduction possible within a particular building. The absence of these split data, as seen for other administration building, (e.g., Figure 14), may indicate poor energy conservation during unoccupied periods.

3 TIME SERIES ANALYSIS

The primary purpose of the time series analysis was to characterize the typical daily electric energy consumption patterns for the various types of Army buildings. A secondary purpose was to examine possible application of a more detailed time series analysis in forecasting energy consumption (as might be used by an EMCS system). A third purpose was to examine the accuracy of short-term electrical metering in predicting annual energy consumption.

Characterization of Daily Profiles

Family Housing

Figure 15 shows typical daily electric consumption profiles for family housing. These profiles were derived through a Fourier analysis of the data, which indicated the dominant frequencies that make up daily consumption. The analysis provided a "typical" profile for each building, even when the day-to-day trend varied somewhat throughout the year. As shown in Figure 15, daily consumption trends in family housing units are very similar. Peak consumption for most units is between 1900 and 2300 hours. It is also interesting to note the difference in profile between an air-conditioned and non-air-conditioned building. Building 214 is air-conditioned, but Building 116 is not. Note that although their profiles are similar, the consumption by Building 214 at 0100 hours is as large as it is at 1000 hours, whereas Building 116's consumption at 1000 hours is near minimum.

The profiles for weekend energy consumption do not vary much from the weekday profiles. In some cases, there is a smoothing of the double peak seen in the weekday trend, but like the weekday trend, the daily peak occurs between 1900 and 2300 hours. Table 7 compares the amplitude of the weekday and weekend peaks; in most cases, there is no great difference. The table also shows the ratio of total to peak electrical consumption. Table 8 gives the coefficients of the equation representing the daily electrical consumption for weekdays and weekends.

Troop Housing

The consumption pattern for the troop housing studied was similar to that of family housing. The peak occurs between 1900 and 2300 hours for both weekdays and weekends. The weekday pattern for troop housing is lower from 0100 to 1600 hours than for family housing. The rise to peak in troop housing begins at 1600 hours. The consumption pattern for weekends is nearly identical to that obtained for family housing, indicating perhaps that it is occupants' activities more than building type which influences energy consumption.

Figure 16 illustrates the electrical consumption patterns for troop housing. Table 8 gives the coefficients of the equations representing the hourly electrical consumption for weekdays and weekends.

As shown in Table 9, the weekday peaks for the buildings analyzed were higher than the weekend peaks. However, the weekend totals were higher than the weekday totals for three of the four buildings.

Dining Facilities

Figure 17 shows typical daily electric consumption profiles for dining facilities. Three of the dining facilities analyzed have a very characteristic "three-meal-a-day" weekday pattern. The fourth facility has a nondescript weekday pattern. One explanation for this behavior is that the three facilities with a very pronounced pattern may have very specific mealtimes. The fourth facility, an enlisted open mess, probably has more flexible operating hours.

The weekend patterns tend to support this idea. Data points 131 and 130, which have pronounced weekday patterns, have a less pronouned weekend pattern. Data point 333, which also has a pronounced weekday pattern, has a weekend pattern which is very similar to the weekday pattern of data point 241. This is probably due to a more flexible meal schedule on weekends. Table 8 gives the coefficients of the equations representing the hourly electrical consumption for dining facilities.

Table 7
Family Housing–Comparison of Weekday and Weekend Peaks (KW) and Total Consumption (KWh)

	Weekday		Ratio	Weekend		Ratio
Building	Peak	Total	Total/Peak	Peak	Total	Total/Peak
214	3.05	52.29	17.14	3.25	52.57	16.17
210	2.80	49.24	17.58	2.75	48.62	17.68
204	2.95	53.03	17.97	3.11	50.25	16.15
211	2.57	43.86	17.06	2.34	44.32	18.94
122	4.60	74.45	16.18	3.90	64.11	16.43
116	0.94	15.82	16.82	0.92	16.05	17.44
205	1.3	22.51	17.31	1.24	21.50	17.33
110	2.42	36.41	15.04	2.24	32.63	14.56

Table 8
Equation and Coefficients for Determination of Daily Electricity Consumption Patterns

Equation:

$$E_{eh} = M_{eh} + a_1 \sin\left(\frac{2\pi}{24}t - b_1\right) + a_2 \sin\left(\frac{2\pi}{12}t - b_2\right) + a_3 \sin\left(\frac{2\pi}{8}t - b_3\right) + a_4 \sin\left(\frac{2\pi}{6}t - b_4\right) + a_5 \sin\left(\frac{2\pi}{4.8}t - b_5\right)$$

where

E_{eh}	= hourly electrical consumption	(kWH)
M_{eh}	= mean of hourly consumption	(kWH)
a_i	= Amplitude of period i	(kWH)
b_i	= Phase of period i	(radians)
t	= hour in question, t = 1,24	(hours)

Troop Housing

Building	M_{eh}	a_1	b_1	a_2	b_2	a_3	b_3	a_4	b_4	a_5	b_5
119 WD	20.5982	3.569	−2.642	3.007	1.261	1.870	.813	−.295			
WE	22.0475	3.831	2.661	1.943	−2.276	.812	1.302	.289	2.135		
127 WD	22.5250	5.336	2.115	1.911	2.817	.947	−2.239	1.375	−.567	1.220	2.169
WE	16.0245	2.324	−2.503	.816	−2.535	.299	2.319				
136 WD	1.2429	0.217	−2.158	.262	3.197	.059	3.126	.067	.152	.027	2.479
WE	1.3034	0.233	−2.535	.162	−2.569	.030	1.051	.039	3.417		
137 WD	1.3766	0.232	−2.347	.205	3.293	.055	3.042	.034	−.113		
WE	1.4656	0.232	−2.811	.119	−2.410	.037	1.740				
339 WD	37.550	4.551	3.189	3.670	3.323	1.174	−2.258	.803	−.305	.766	2.364
WE	35.4767	5.091	3.204	2.370	−1.900	.490	2.417				

Dining Facilities

Building	M_{eh}	a_1	b_1	a_2	b_2	a_3	b_3	a_4	b_4	a_5	b_5
130 WD	19.1436	5.849	1.961	2.519	2.449	.673	−2.145	1.881	−.602	.302	2.790
WE	14.1039	3.512	2.144			.685	−.328			.469	3.620
131 WD	10.306	2.821	1.916	1.382	2.051	.245	−1.732	.887	−.426	.302	3.705
WE	8.7238	2.087	1.829			.639	−.539	.285	2.709		
241 WD	25.888	4.889	2.611	2.238	−1.838	.305	1.468	.341	3.645		
WE	26.8679	3.576	3.233	1.748	−1.550	.772	.122	.594	.584	.448	.387
333 WD	58.817	10.860	1.326	4.104	1.801	1.425	3.138	5.345	−.986	1.658	3.054
WE	54.5594	12.020	1.644	.795	−1.688	4.164	−.429			.9995	3.692

Family Housing

Building	M_{eh}	a_1	b_1	a_2	b_2	a_3	b_3	a_4	b_4	a_5	b_5
110 WD	1.517	.497	2.506	.652	3.060	.136	−.581	.146	1.837	.141	3.147
WE	1.3597	.616	3.136	.423	3.099	.116	.397	.104	2.895	.056	3.840
116 WD	.6591	.194	2.916	.094	2.918	.061	2.131				
WE	.6687	.239	3.007	.085	3.239						
122 WD	3.1020	.779	2.925	.760	3.048	.167	1.985	.178	1.614	.067	2.120
WE	2.6712	.688	3.119	.535	3.413	.275	1.874				
204 WD	2.2095	.940	2.891	.377	2.315			.101	3.145	.129	4.168
WE	2.0939	.848	3.283	.376	−2.325	.139	1.690				
205 WD	.9381	.3345	3.155	.141	3.554						
WE	.8959	.3365	3.401	.085	−2.258						
210 WD	2.0516	.699	2.801	.372	−2.068	.150	2.147	.084	4.095		
WE	2.0258	.821	3.040	.177	−1.779	.120	2.804				
211 WD	1.8277	.542	−2.758	.214	2.895	.149	3.673	.090	.326	.068	2.741
WE	1.8468	.590	−2.864	.124	−1.342						
214 WD	2.1789	.717	3.299	.372	−2.492			.102	3.345		
WE	2.1903	.8206	3.295	.386	−2.218	.143	−1.709	.157	3.411	.129	4.228

Table 8 (Continued)

Administration/Training

Building	M_{eh}	a_1	b_1	a_2	b_2	a_3	b_3	a_4	b_4	a_5	b_5
148 WD	61.7789	27.564	2.025	5.687	−1.732	4.021	−.965	4.438	2.094		
WE	36.585	.928	3.249	.578	−1.363	.509	.074				
153 WD	4.1215	4.118	1.777	1.359	−1.485	.525	−.695	.849	2.005	.449	−1.223
WE	1.0266	.342	.055	.159	−1.216	.101	.196	.307	−.096		
365 WD	12.1827	3.965	1.723	.801	−2.050	1.007	−.969	.489	1.968		
WE	8.7095	.197	−1.353								
Maintenance											
138 WD	25.2679	9.437	1.866	2.501	−1.278	1.837	−.9243	1.951	2.666		
WE	18.042	1.300	2.287	.661	1.731						
139 WD	32.092	7.637	2.072	2.452	1.222	.981	.305	2.260	2.794	1.150	.110
WE	22.6927	2.163	.763	.380	1.518	.472	2.282				
140 WD	336.5468	310.905	1.759	111.610	−1.253	45.249	−1.155	69.283	2.234	12.026	.877
WE	156.6390	39.542	.8325	27.471	−1.533	10.424	3.765				

Table 9
Troop Housing–Comparison of Weekday and Weekend Peaks (kW) and Total Consumption (kWh)

	Weekday		Ratio	Weekend		Ratio
Building	Peak	Total	Total/Peak	Peak	Total	Total/Peak
119	28.5	494.21	17.34	25.75	529.14	20.54
136	1.80	29.83	16.57	1.67	31.28	18.73
137	1.85	33.04	17.85	1.78	35.17	19.75
339	44.5	910.20	20.45	40.5	851.44	21.02

As shown in Table 10, the weekday peak is always greater than the weekend peak. Also, in three out of four cases, the weekday energy consumption is greater than the weekend energy consumption.

Administration

Figure 18 shows typical daily electric consumption profiles for administration buildings. The weekday profiles for all three buildings have a double peak structure. Most of the profile seems to be dominated by occupant behavior. The weekend unoccupied periods show a flat consumption profile; the level of consumption corresponds approximately to the weekday minimum. Because this baseload consumption is well above zero, it indicates an opportunity for energy conservation. Table 11 gives the weekday and weekend peaks and totals.

Maintenance

The weekday energy consumption pattern for maintenance facilities is nearly identical to that of administration facilities (see Figure 19). Once again, even though there are order-of-magnitude differences in the absolute level of consumption, the profiles for all the maintenance buildings are very similar; all exhibit a large baseload.

The weekend patterns for Maintenance Buildings 138 and 139 indicate fluctuation caused by HVAC control, such as fans and pumps turning on and off, since the total fluctuation is about 4 to 5 kWh. Building 140 has a pattern which is difficult to explain unless some type of weekend maintenance work is performed. The high level of weekend consumption when the buildings should be unoccupied indicates potential for energy conservation. Table 12 gives the weekday and weekend peaks and consumption totals.

Forecasting

A second aspect of time series analysis which was investigated was its use as a predictive tool. This is

Table 10
Dining Facilities
Peaks (kW) and Total Consumption (kWh)

Building	Weekday Peak	Weekday Total	Ratio Total/Peak	Weekend Peak	Weekend Total	Ratio Total/Peak
130	24.5	459.45	18.75	17.25	338.49	19.62
131	13.0	247.34	19.02	11.0	209.37	19.03
241	31.25	621.31	19.88	30.0	644.83	21.49
333	73.0	1411.61	19.33	68.5	1309.43	19.10

Table 11
Administrative Buildings—Comparison of Weekday and Weekend
Peaks (kW) and Total Consumption (kWh)

Building	Weekday Peak	Weekday Total	Ratio Total/Peak	Weekend Peak	Weekend Total	Ratio Total/Peak
148	92	1482.7	16.11	38	878.0	23.0
153	9.1	98.92	10.87	1.5	24.6	16.4
365	17	292.4	17.20	9.5	209.0	22.0

Table 12
Maintenance Buildings—Comparison of Weekday and
Weekend Peaks (kW) and Total Consumption (kWh)

Building	Weekday Peak	Weekday Total	Ratio Total/Peak	Weekend Peak	Weekend Total	Ratio Total/Peak
138	36	606.43	16.85	20	433.01	21.65
139	42	770.21	18.34	25	544.62	21.78
140	705	8077.12	11.46	207	3759.34	18.16

the classic application of time series analysis, as opposed to the characterization work which is primarily concerned with determining the data's sinusoidal components. The forecasting work uses these sinusoids and the random (stochastic) component of the data to predict future consumption.

The unit cost of purchased electricity depends on the peak demand. The higher the peak demand, the higher the cost per kilowatt hour. Total electric cost can be reduced by reducing peak demand even if total consumption remains constant. If peak demand can be anticipated, then electric load can be shed and the peak reduced.

The objective of the forecasting portion of the analysis was to demonstrate that a model could be developed which could forecast future hourly electrical load with enough accuracy to manage energy consumption. The approach used was to identify candidate time series models using a computer code known as DDS and then evaluate their forecasting ability over both the original data and a future data set.

Candidate models were developed using hourly electrical consumption for Building 2060 at Fort Carson, CO, from 1 a.m. on Monday, 1 August 1977, to midnight on Friday, 12 August 1977. Figure 20 is a plot of this data. Weekends and holidays were removed from the data, since the building is an administration building which is used primarily on weekdays. Candidate models were then developed and evaluated which forecasted electrical consumption for 1 through 24 hours both over the original data set (1 August 1977 to 12 August 1977) and over a future data set for 15 August 1977 to 26 August 1977.

The resulting form of the model is known as a deterministic plus stochastic model. The deterministic portion of the model is made up of sinusoidal (in this case, the 24-hour fundamental and the 12-, 8-, and 6-hour) harmonics. The stochastic form of the model consists of an ARMA* (5,2). The basis of the ARMA model is that the value of the function at any time depends on the function's previous values. The degree of the model indicates how many past values are needed to predict the present value. The behavior of the model which was developed can be observed by comparing the actual data in Figure 20 with the prediction of the model shown in Figure 21. Figure 22 shows the error between the actual data and the model. As shown in Figure 22, the prediction error increases as the forecast lead time increases. Comparison of the model with the data used to generate it is a first step in determining its adequacy. The final test is an evaluation of the model's ability to make predictions against a future data set. Figure 23 is a plot of the future data set. Figure 24 is a plot of the model's prediction of the future data set. The error in predicting the future data set is shown in Figure 25. Again, the prediction error increases as the forecast lead time increases. The standard error associated with one-step-ahead forecasts with this model results in an accuracy of ± 3 kWh in the model's prediction. This is about 10 percent of the peak amplitude and should be accurate enough to manage energy consumption.

Short-Term Metering

A third application of the time series analysis was its use in short-term metering. Conservation of electrical energy is important within the Army, but it can be difficult. Part of the problem is that many buildings do not have electrical meters. It is hard to reduce the total utility bill when little is known about individual building consumption.

One feasible solution to this problem is using clamp-on, short-term metering for sampling. This idea is becoming popular as a way of inducing different groups on post to compete in energy conservation. The basic idea behind short-term metering is that a short-term measurement can provide a reasonable estimate of a building's overall energy consumption over a longer period of time. Time series analysis was examined as a way to determine how short a metering period could be used and what kind of accuracies might be expected in projecting the short-term measurements over a longer period of time.

The first step is the development of a time series model for a particular building's electrical consumption. This analysis used daily electrical energy consumption figures for a Fort Belvoir family housing unit during the 1977–1978 heating season (see Figure 26). The time series model had a deterministic portion and a stochastic portion. The deterministic portion was developed through Fourier series analysis and was used to determine the data's sinusoidal behavior. The stochastic portion was developed by using an ARMA model to reflect the dependence of a present data value on some set of past data values. Figure 27 shows the results of the Fourier analysis. The solid horizontal line indicates a 99 percent confidence limit of significance, while the dashed line indicates 95 percent limits. One cycle per sample period proved to be significant, explaining 41 percent of the variance in the data. This phenomenon may be explained by the increased lighting demands during December and January. Three cycles per sampling period achieved the 95 percent limit; however, this period explained only 6.9 percent of the total variance. An analysis showed significance for both three and two cycles per sample period using the F-test. However, three and two cycles per heating season were unexplainable phenomena; therefore, these periodicities were regarded as purely stochastic behavior.

Hence, to acquire stationary figures, period 272 was removed from the data. Residuals were plotted to visually check data stationarity (see Figure 28). The data were then prepared for DDS stochastic modeling.

The stochastic modeling strategy involved successively fitting of ARMA $(2n, 2n-1)$, $n = 1, 2, \ldots$ using the DDS computer program, until AIC, Chi-square, and F-test criteria were satisfied. ARMA (5,5) resulted in a minimal AIC value, and the reduction of a parameter proved insignificant according to the F-test. Phi (5) and Theta (5) were both statistically significant for ARMA (5,5). Therefore, ARMA (5,5) was chosen as an initial adequate model. The combined results of the Fourier and ARMA analyses make up a mathematical model for the family housing unit's electrical energy consumption behavior.

This model can now be used to provide the statistics and parameters required to estimate sample

*Auto Regressive Moving Average.

sizes and accuracies expected from a short-term monitoring effort. CERL Technical Report N-101[12] indicates that the variance of $\bar{X}$ may be calculated using the parameters of the fitted ARMA (n,m) model (see Appendix A). Using this variance will take into account the continuity of sampling, rather than the necessity of performing a random sample and using the conventional variance. DDS shows that the Var $(\bar{X})$ equals 4.5267.

DDS supplies the sample size, N, required to achieve a 95 percent confidence interval plus or minus 50 percent of the mean. This value is listed on the output as N $(.5\bar{X})$ Appendix A shows the method for calculating N. Since N is inversely proportional to the square of $X - \bar{X}$, the tighter one wishes to predict the mean, the greater the value of N.

Table 13 displays the various N requirements, given a number of different constraints on the confidence interval. For example, 95 times out of 100, the average for 72 days of continuous sampling of heating season electrical consumption (or 2.4 months) will fall within 25 percent of the true average electrical consumption for that heating season.

[12]P. D. Schomer, et al., *Temporal Sampling Requirements for Estimating the Mean Noise Level in the Vicinity of Military Installations,* Technical Report N-101/ADA099801 (CERL, 1981).

Table 13
N Requirements

% Error on Average	Required N (days)
50	18
40	28
30	50
25	72
20	113

To test the results of the analysis, data from two other family housing units were analyzed. Segments of data 18 days long were taken, and averages were determined at various times during the heating season. The averages were corrected for the annual sinusoidal variation (e.g., the deterministic portion of the mathematical model), using Eq 16.

$$E_c = E - 9.1138 \sin\left(\frac{2\pi}{272}t - 1.3882\right) \quad \text{[Eq 16]}$$

Table 14 gives the results of this test.

The length of the sample period used in Table 14 is 18 days. Table 13 shows that the expected error is ±50 percent, yet the largest error encountered in this

Table 14
Heating Season Electrical Consumption Prediction Errors

Building	Sampling Period	Estimated Heating Season Average Electrical Consumption	Actual	% Error
210	23 Sep-10 Oct	39.024	44.20	11.7
210	19 Oct-5 Nov	44.47	44.20	0.6
210	18 Nov-5 Dec	45.12	44.20	2.1
210	28 Nov-15 Dec	43.32	44.70	2.0
210	8 Jan-25 Jan	38.98	44.20	11.8
210	17 Feb-6 Mar	40.65	44.20	8.0
210	10 Mar-27 Mar	40.57	44.20	8.2
210	24 Apr-11 May	50.64	44.20	14.6
210	5 May-22 May	52.52	44.20	18.8
210	23 May-9 Jun	52.48	44.20	18.7
204	1 Oct-18 Oct	33.99	37.06	-8.3
204	2 Apr-19 Apr	34.98	37.06	-5.6
204	16 Jan-2 Feb	35.75	37.06	3.6
204	18 Nov-5 Dec	39.26	37.06	5.9
204	6 Dec-23 Dec	35.61	37.06	-3.9
204	10 May-27 May	43.86	37.06	18.3

test was +18.81 percent. Investigation[13] indicated that the method of calculating N which was used will overestimate N if any sinusoidal components remain in the data. This is the suspected cause of the discrepancy between the estimated and actual errors.

The conclusion to be drawn from the analysis is that the actual error experienced for a sample period of length N may be better than predicted. Based on the data presented here, a sample period of 18 days appears adequate to make energy consumption predictions of ±18 percent for a family housing heating season, if the data are corrected for seasonal trends. Since it appears that the seasonal trends for family housing units at one post are all very similar, it should be possible to monitor one unit on a daily basis for 1 year, use these data to determine seasonality, and then conduct short-term measurements on the other units.

4 CONCLUSIONS AND RECOMMENDATIONS

The results of regression analysis indicate that simple, easy-to-use relationships can be determined for Army facilities' energy consumption, based on heating and cooling degree days. These relationships can be used to estimate energy consumption for aggregates of 10 or more buildings. The methods can be used for estimating energy consumption in all types of buildings, including family housing, troop housing, administration/training facilities, dining facilities, medical/dental facilities, product maintenance facilities, community facilities, and storage facilities.

The analysis of scatterplots indicates that the observed patterns of energy consumption often cross building type categories and may provide a way to assess various methods of energy conservation. Furthermore, the analysis of scatterplots indicates that the patterns observed were common to buildings at all three posts; this confirms the assumption that Army buildings are very similar.

The characterization of daily electrical consumption which was done as part of the time series analysis provides information on the timing and magnitudes of electrical consumption peaks for the various building categories. The ratio of total daily electrical consumption to hourly peak consumption was found to be about 18 for the buildings surveyed. The information provided should be useful to the DEH engineer in developing daily load shedding plans and to the District Engineer in using computer-based energy estimation tools to program the timing of internal gains.

The results of the time series analysis to develop criteria for short-term metering showed that accurate, short-term metering is feasible in Army buildings.

It is recommended that DEH, MACOM, and District engineers use the results of the analysis presented in this report to estimate the energy consumption of groups of buildings. There are a number of areas to which these results can be applied.

1. The regression equations summarized in Table 15 can be applied to mobilization planning by projecting energy impacts from changes in facility active square footage. They can also be used to project energy impacts of National Guard or tenant activities, estimate utility use during weather changes, estimate the amount of post process energy, and serve as an element of Energy Engineering Analysis Programs.

2. As indicated in the time series analysis section, it is possible to accurately estimate an individual building's daily average electrical consumption from short-term metering. If the DEH has daily energy consumption data for a building typical of a particular building type of interest, he/she may subject the data to time series analysis. The analysis can be done by FE personnel or by a private contractor. Once such an analysis is complete and the seasonal trend is determined for that building type, accurate short-term metering can be performed for any building of that type on the post.

It is also recommended that the daily electrical consumption profiles presented in the characterization section be used as an aid to load management.

[13]Personal communication between B. Sliwinski (CERL) and Dr. S. Kapoor (University of Illinois).

Table 15
Summary of Regression Equations

Heating

$$E_h \text{ (Btu/sq ft/day)} = a_1 + b_1 \times (HDD_d)$$

	a_1	b_1	Accuracy (btu/sq ft/day) Individual	Group
Family Housing	113.5	16.5	±200	±24
Troop Housing (Pre-1966)	130.5	15.9	±200	±20
Troop Housing (New)	81.9	7.4	±125	±16
*Troop Housing (Modular)	295.9	34.3	±340	±60
Admin/Training	75.7	18.9	±280	±20
Dining	241.9	0.0		±182
Med/Dental	254.4	24.3	±520	±64
Prod/Maintenance	91.5	31.4	±720	±72
Fieldhouse/Gyms	73.7	32.4	±460	±40
Commissary	147.0	14.2	±380	±36
Storage	35.7	36.1	±520	±80

Electrical

$$E_e \text{ (kWh/sq ft/day)} = a_2 + b_2 \times (CDD_d)$$

	a_2	b_2	Accuracy (kWh/sq ft/day) Individual	Group
Family Housing (air cond)	.0136	.00172	±.02	±.0016
Family Housing (non-air cond)	.0166			±.0008
Troop Housing (air cond)	.0157	.00149	±.016	±.0020
Troop Housing (non-air cond)	.0152			±.0037
Troop Housing (non-air add)	.0065			±.0026
Admin/Training (May-Sep)	.0512			±.014
Admin/Training (Oct-Apr)	.0215			±.005
Med/Dental (May-Sep)	.0557			±.03
Med/Dental (Oct-Apr)	.0353			±.01
Prod/Maintenance	.0264			±.008
Storage	.0141			±.005

Community Facilities Electrical Consumption

Building	Type	Consumption (kWh/sq ft/day)	Accuracy (kWh/sq ft/day)
143	Commissary	.09720	±.010
149	Commissary Annex	.2130	±.010
220	Commissary	.1495	±.013
227	Swimming Pool	.0191	±.006
239	Theater	.0319	±.016
336	Branch PX	.0610	±.015
354	Commissary	.0816	±.023
364	Gymnasium	.0139	±.002
375	Field House	.0354	±.010
362	Community Center (Summer)	.0709	±.002
362	Community Center (Winter)	.0446	±.010
376	Main PX (Summer)	.0345	±.009
376	Main PX (Winter)	.0202	±.003

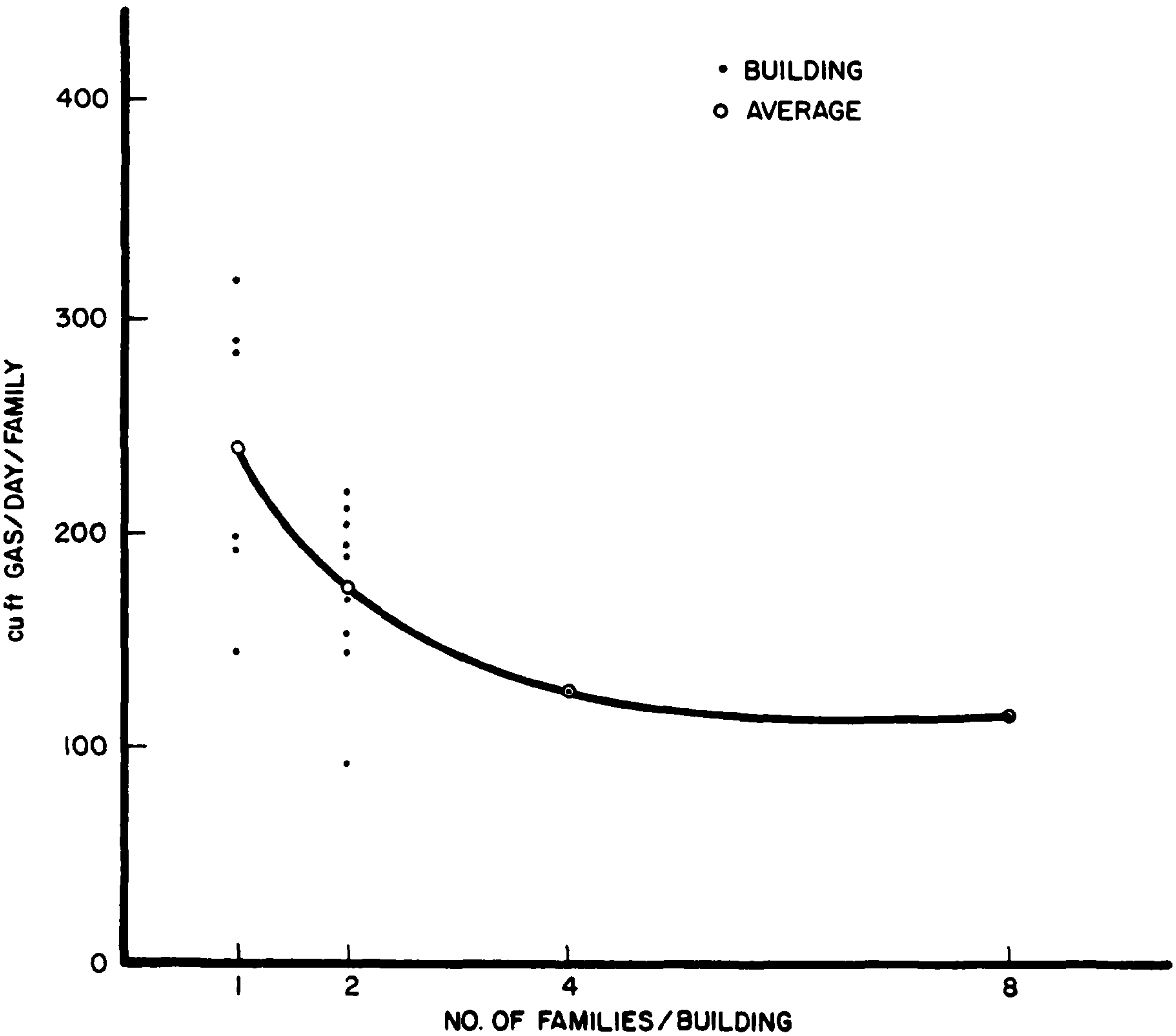


Figure 1. Constant of gas consumption per day per family.

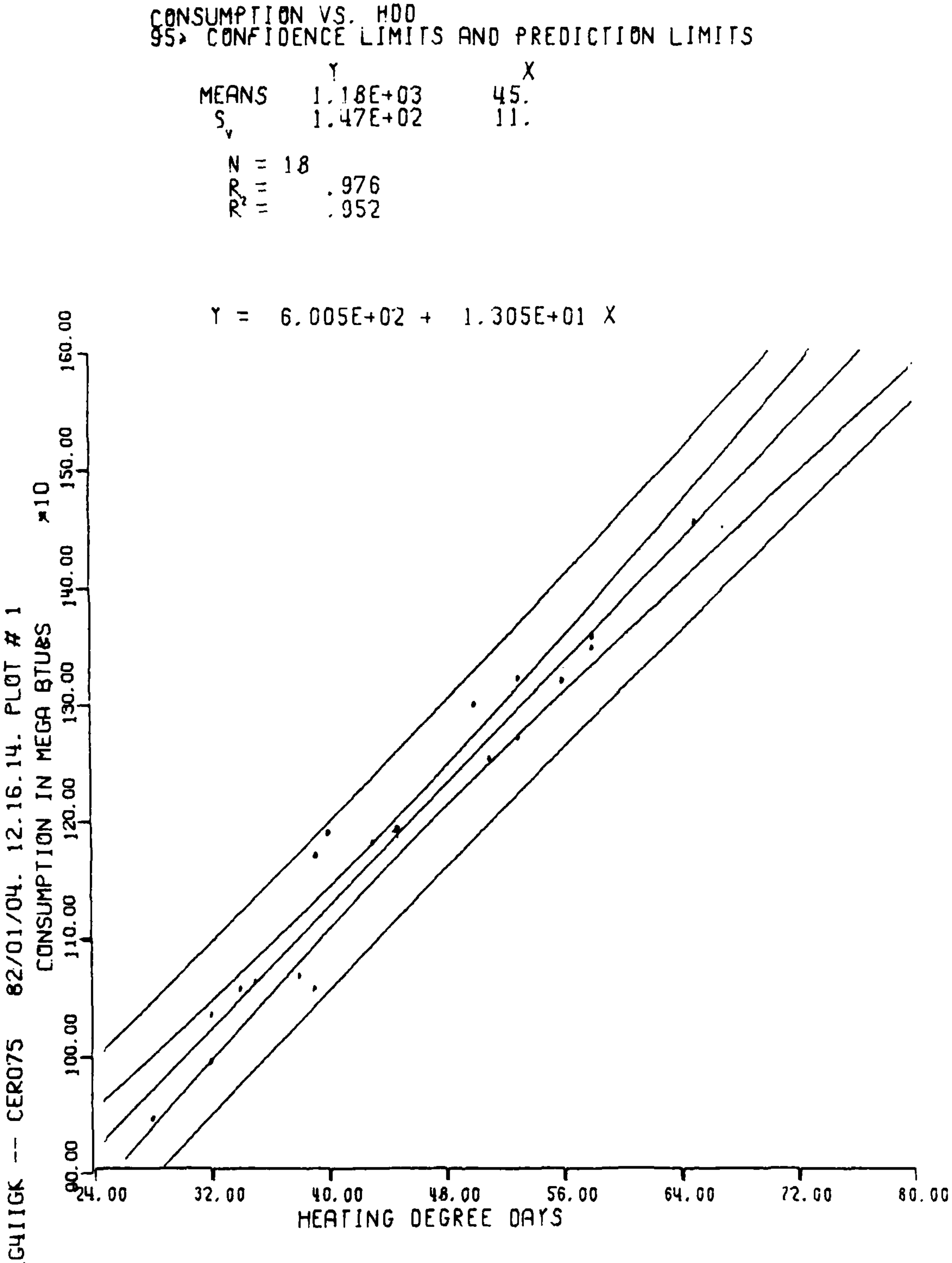


Figure 2. Consumption versus heating degree days (January 1979).

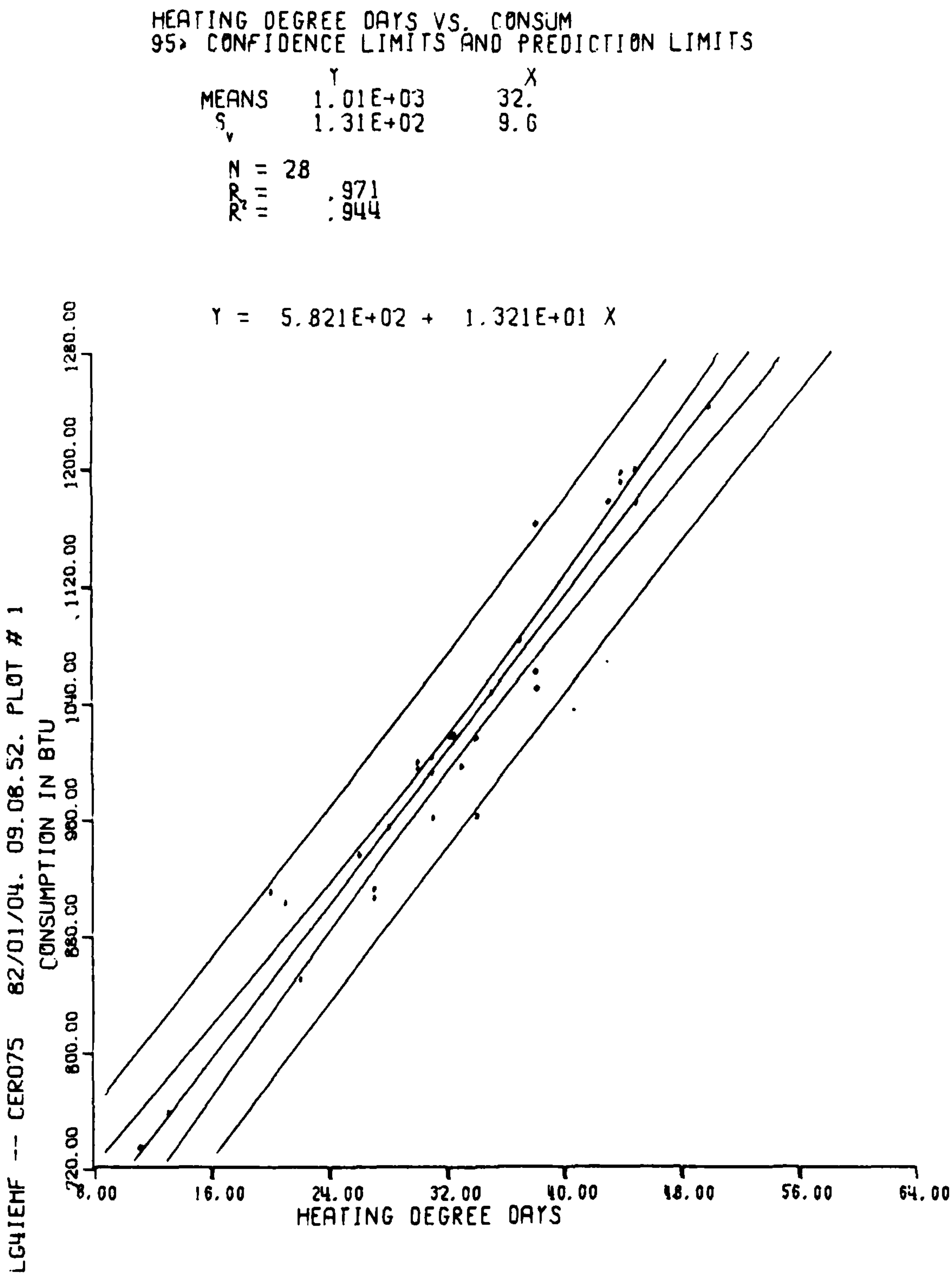


Figure 3. Consumption versus heating degree days (February 1979).

HEATING DEGREE DAYS VS. CONSUM
95% CONFIDENCE LIMITS AND PREDICTION LIMITS

	Y	X
MEANS	9.15E+02	29.
S_v	1.11E+02	6.5

N = 24
R = .916
R^2 = .838

$Y = 4.634E+02 + 1.574E+01\ X$

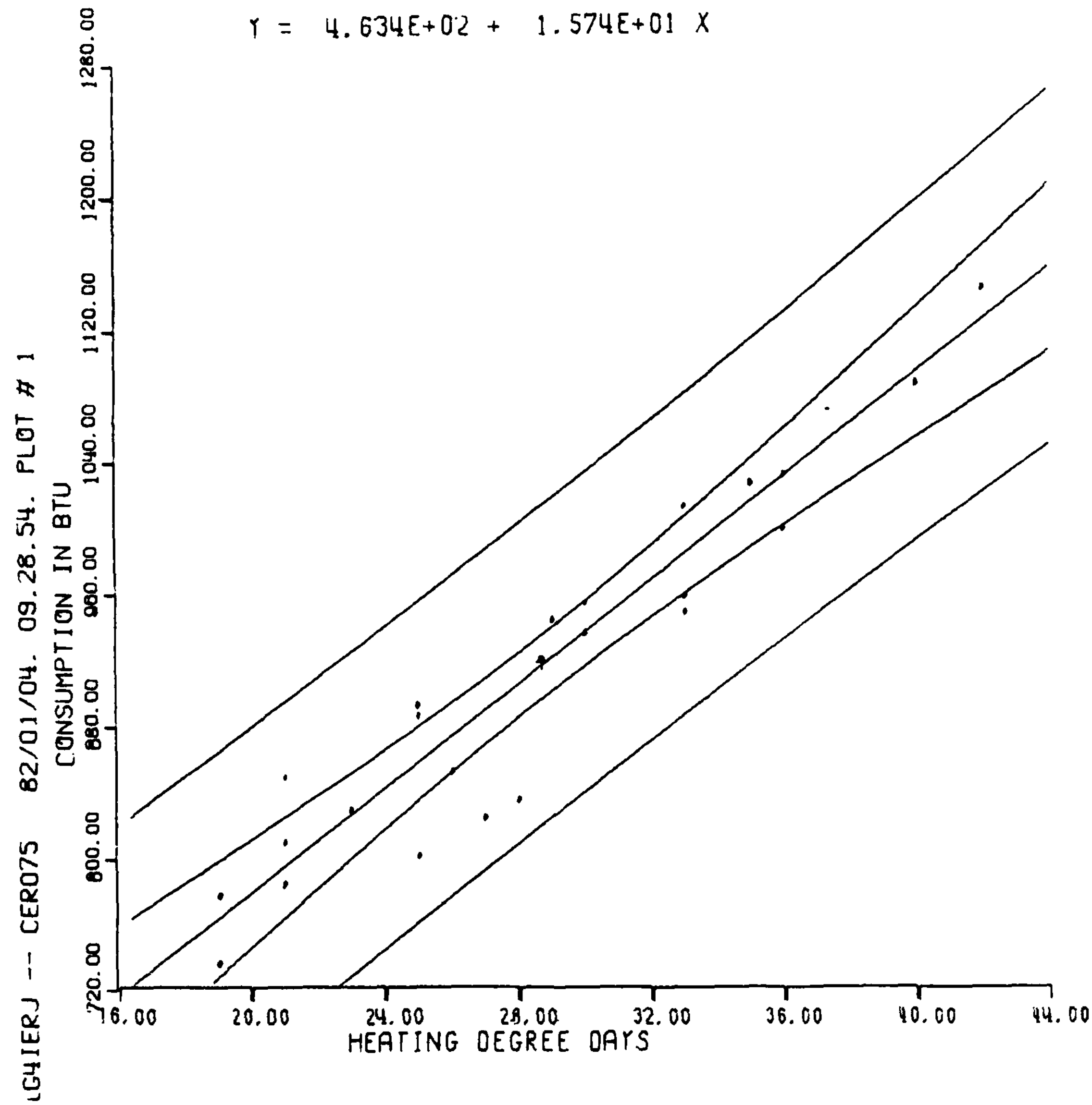


Figure 4. Consumption versus heating degree days (March 1979).

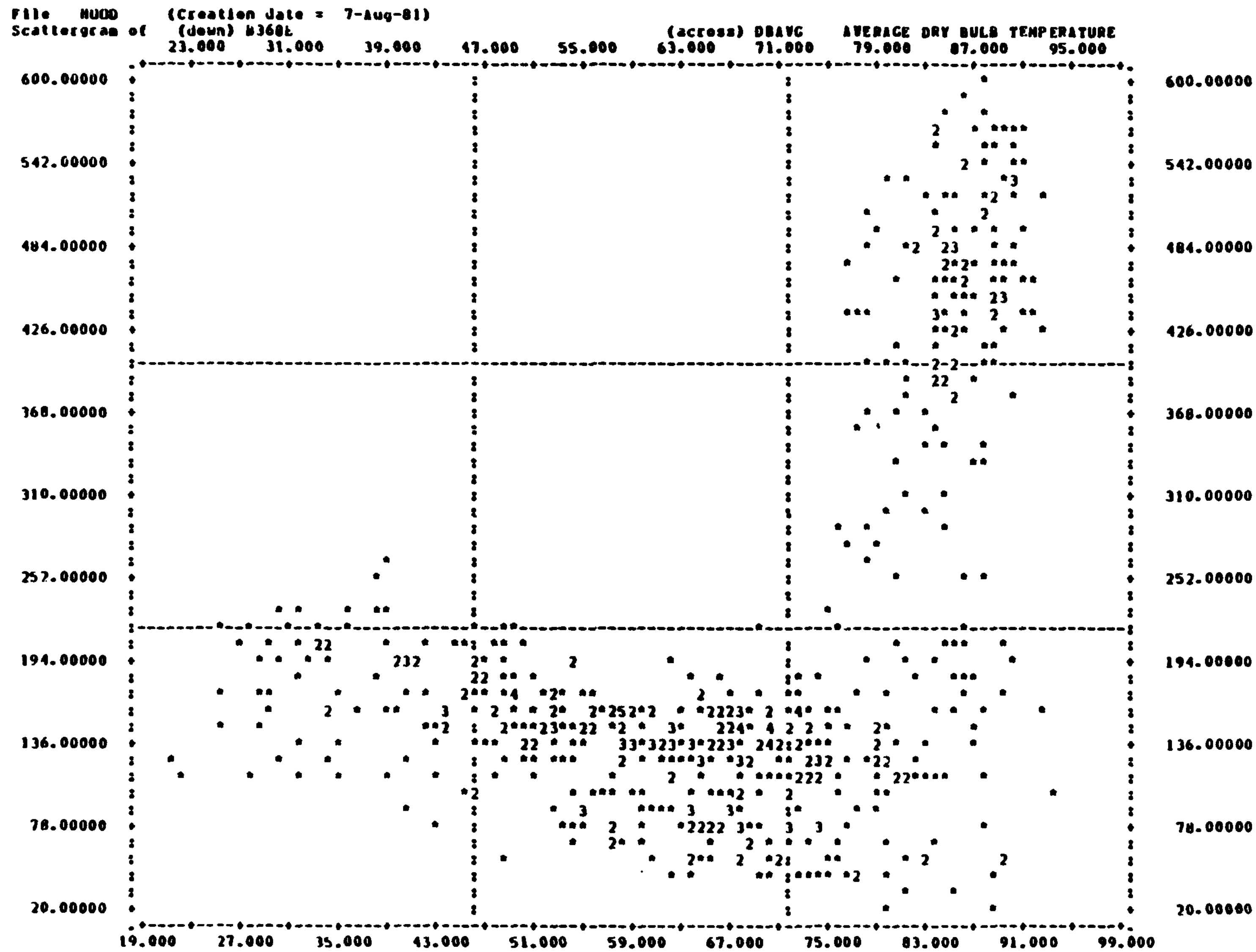


Figure 5. Scatterplots of Hood variables versus DBAVG.

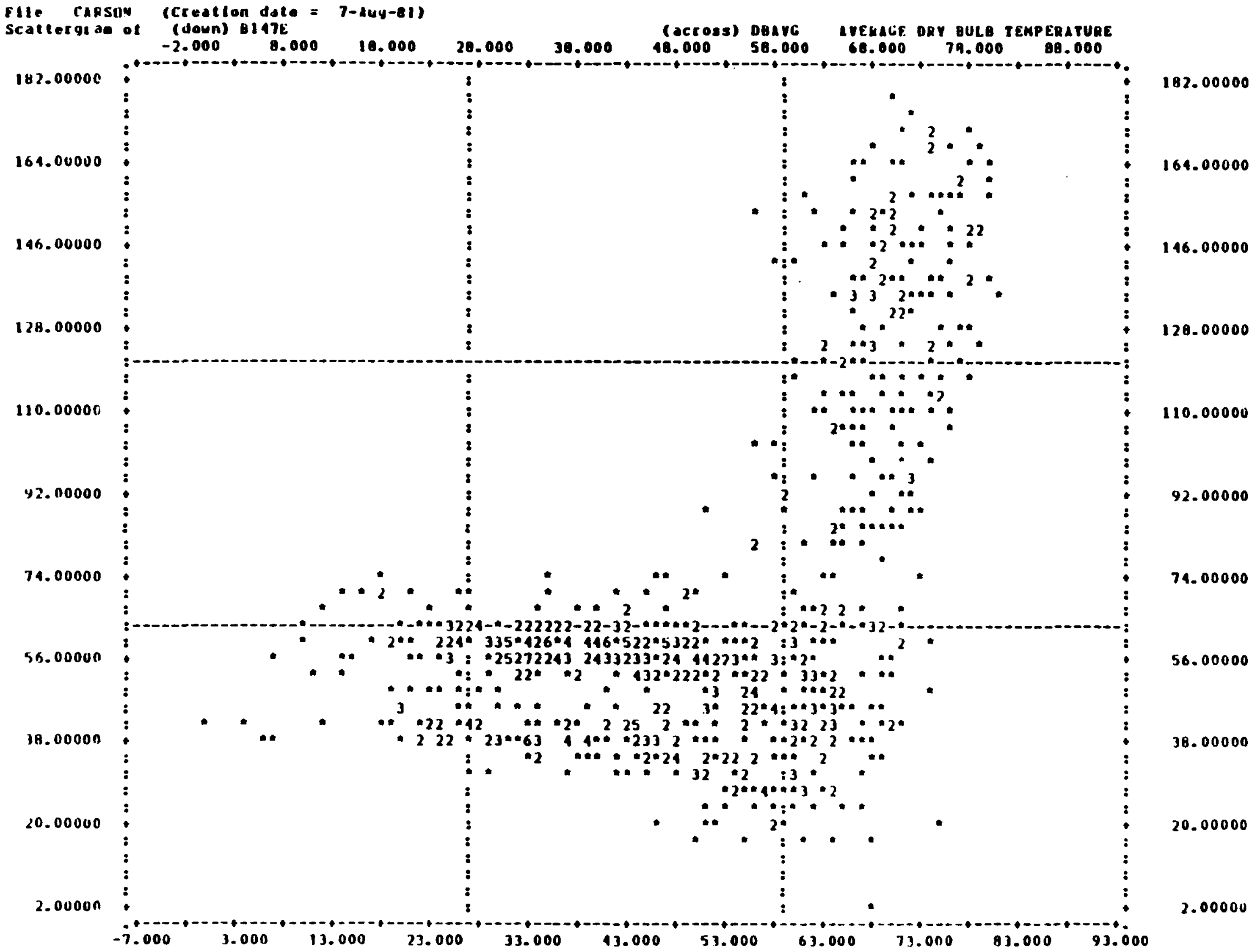


Figure 6. Scatterplots of Carson variables versus DBAVG.

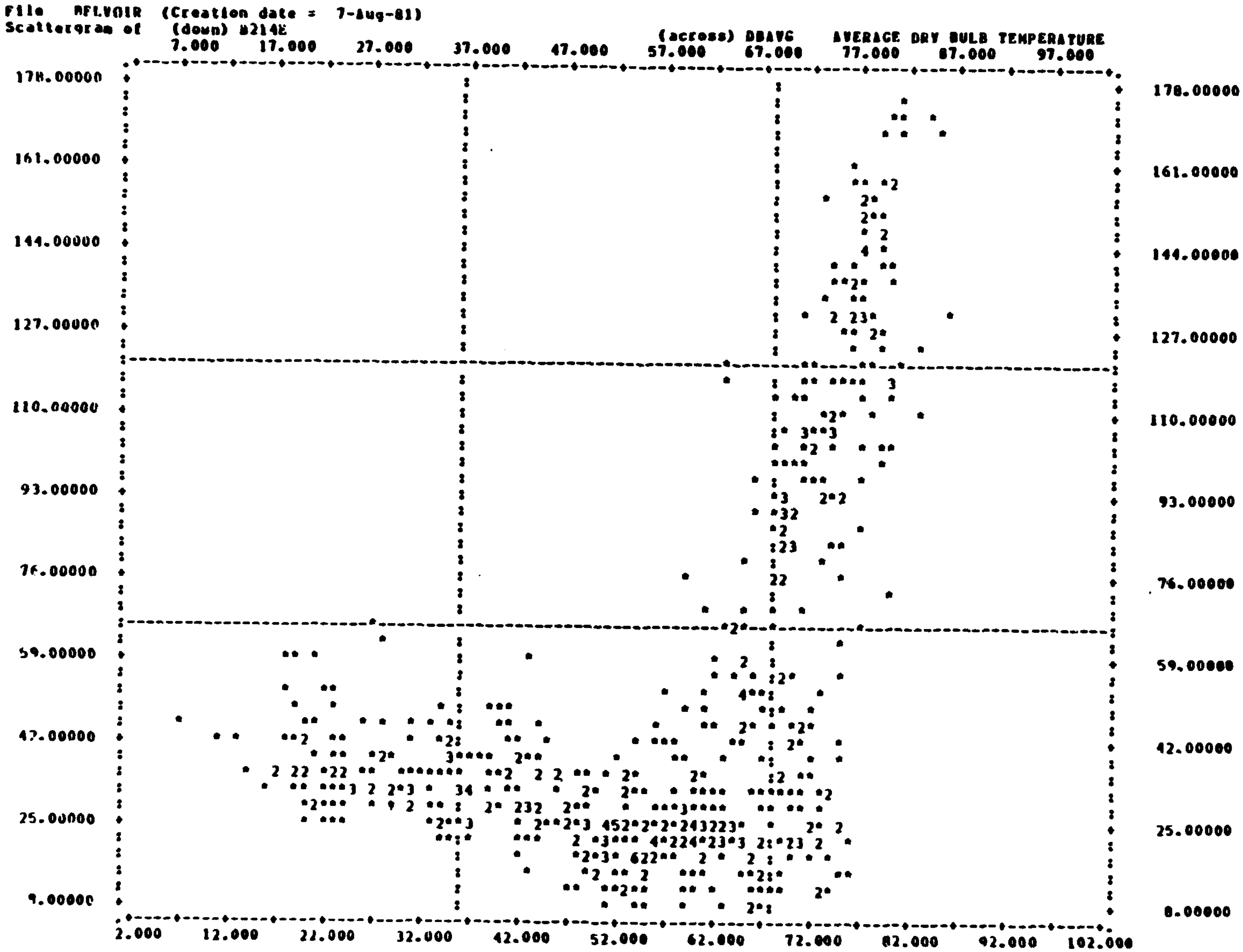


Figure 7. Scatterplots of Belvoir variables versus DBAVG.

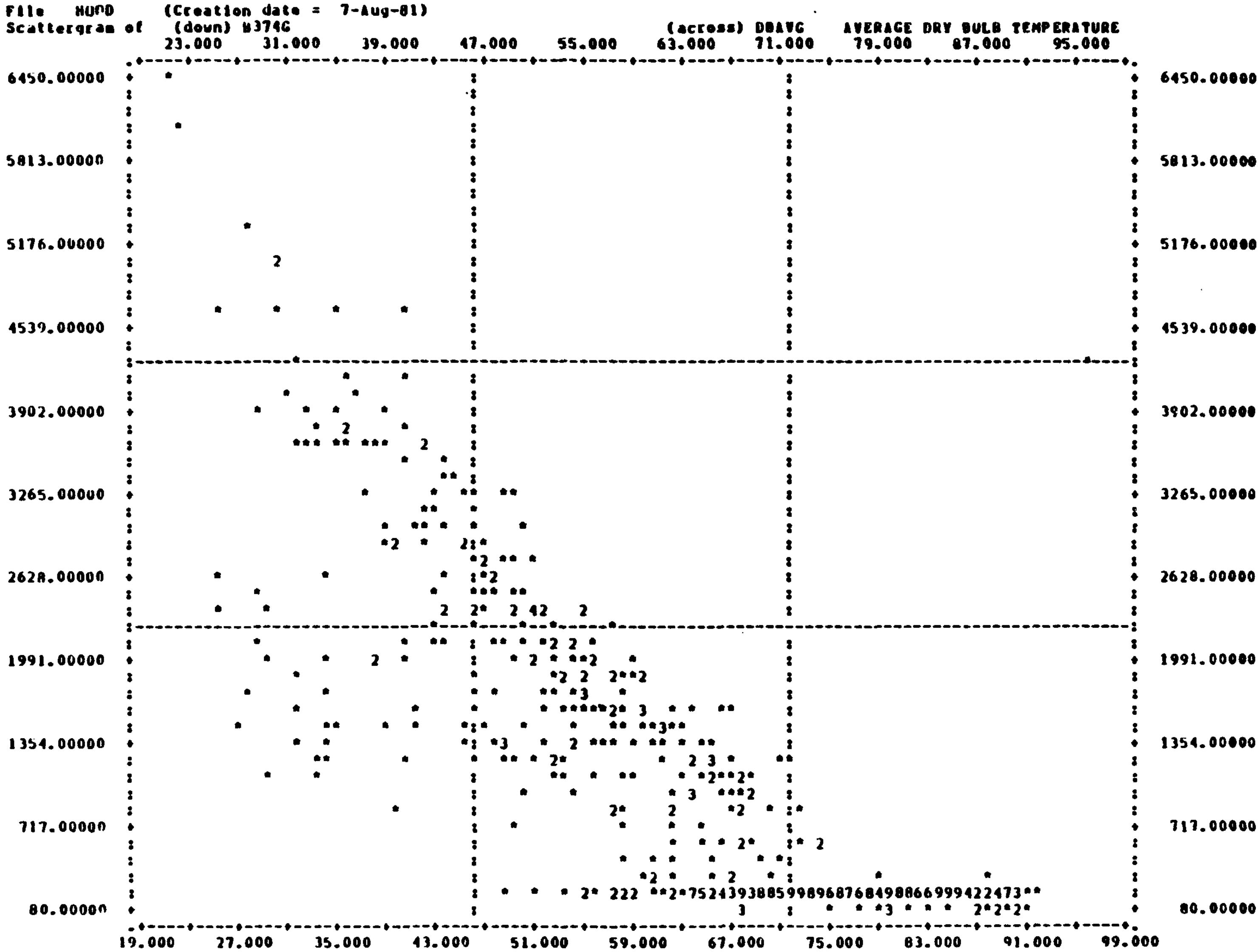


Figure 8. Scatterplots of Hood variables versus DBAVG.

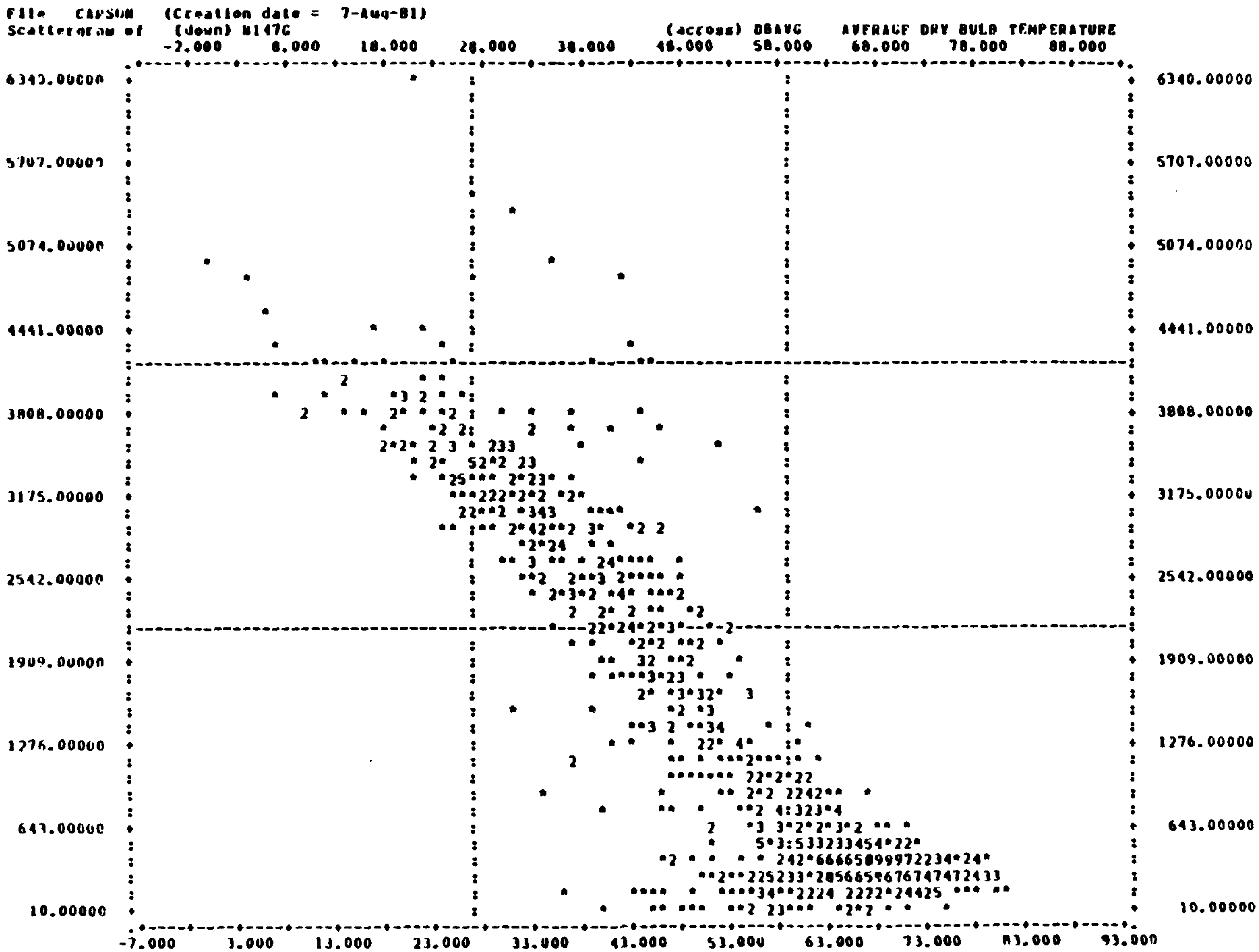


Figure 9. Scatterplots of Carson variables versus DBAVG.

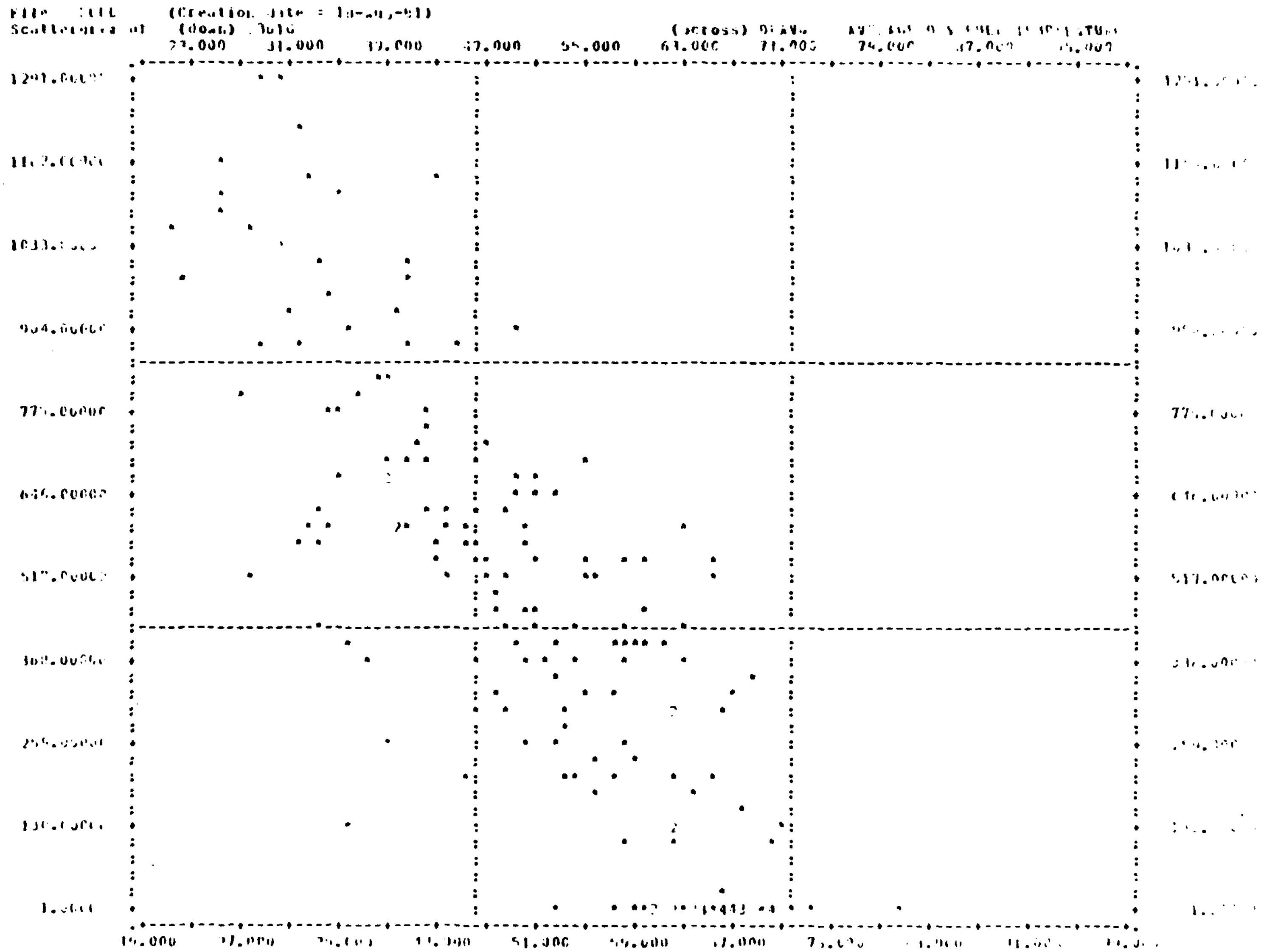


Figure 10. Additional scatterplots of Hood variables versus DBAVG.

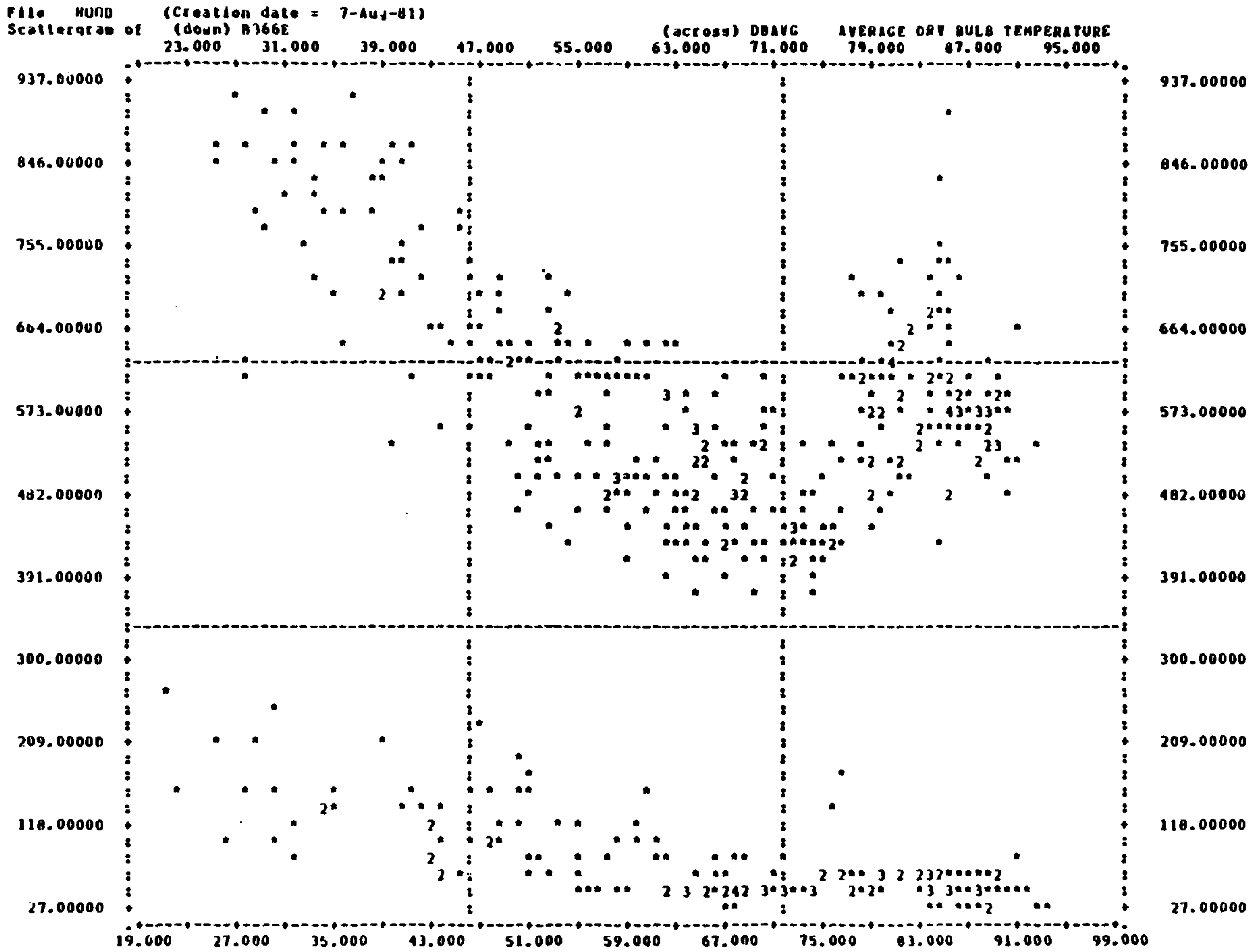


Figure 11. Scatterplots of Hood variables versus DBAVG.

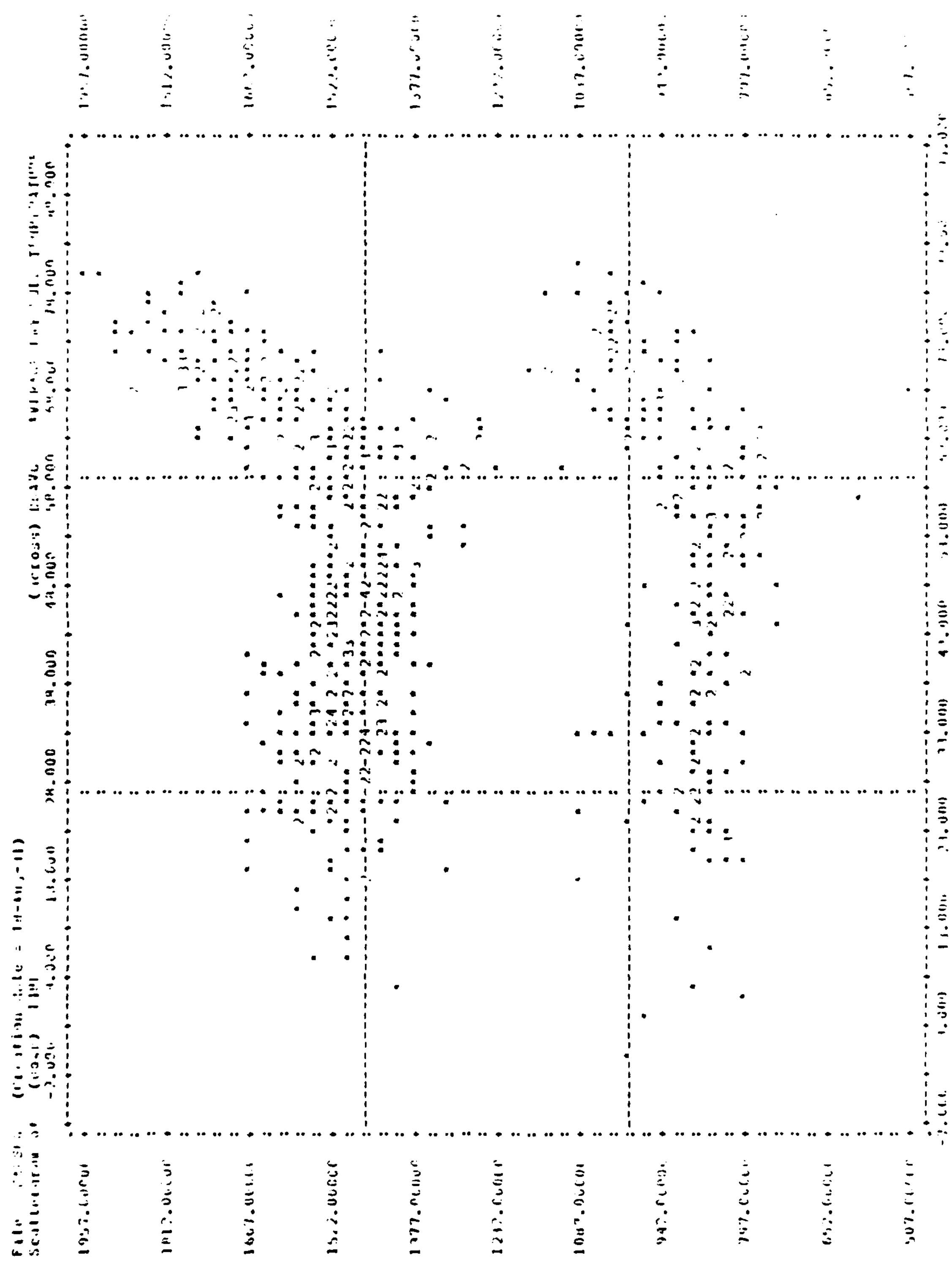


Figure 12. Additional scatterplots of Carson variables versus DBAVG.

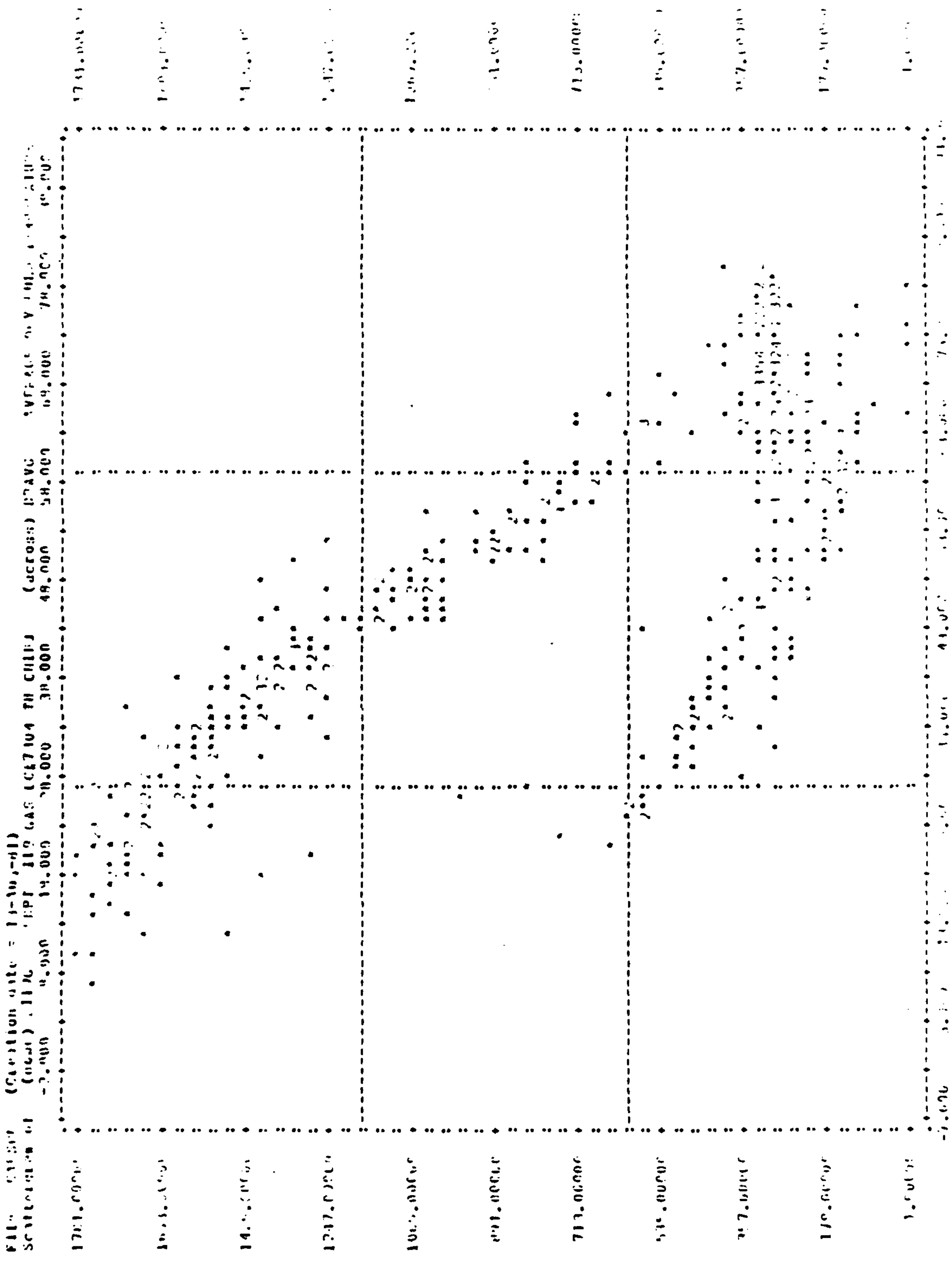


Figure 13. Additional scatterplots of Carson variables versus DBAVG.

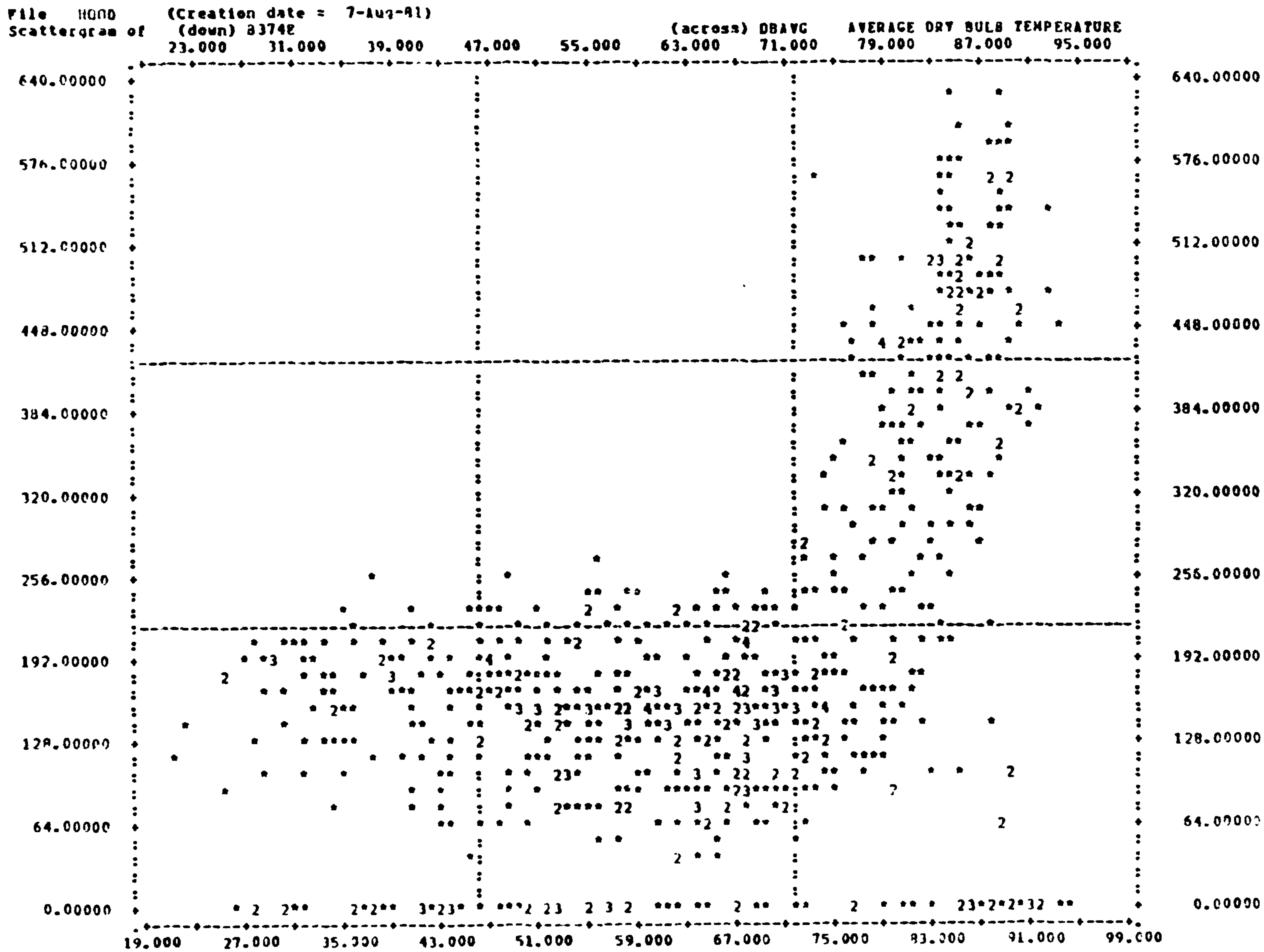
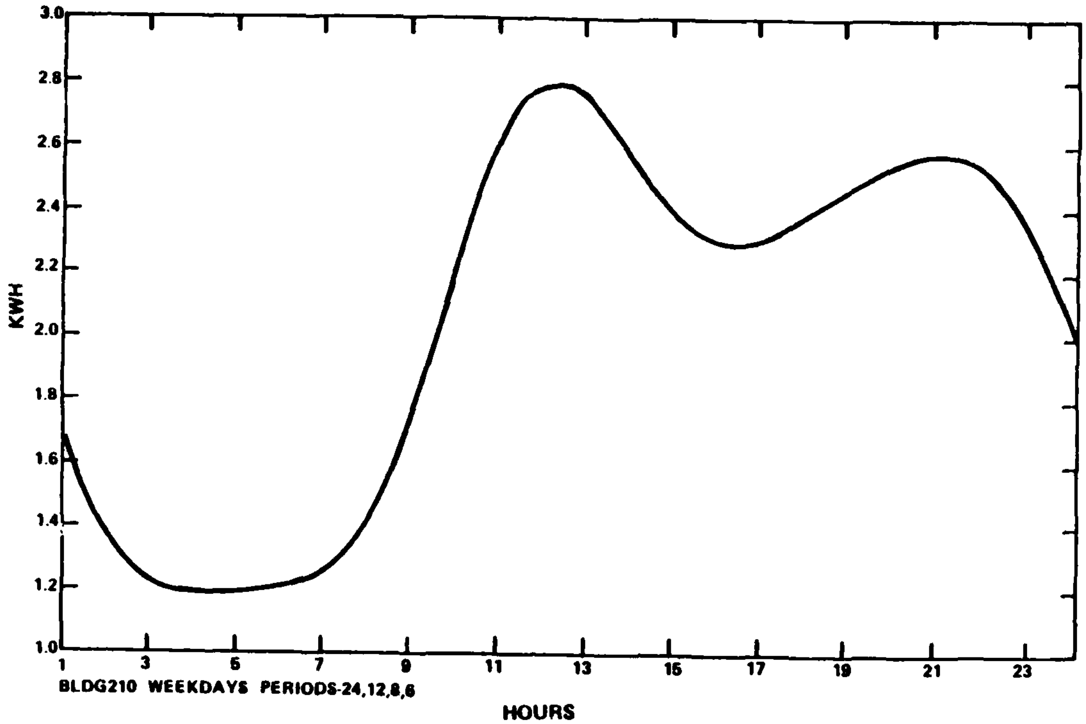


Figure 14. Scatterplots of Hood variables versus DBAVG.



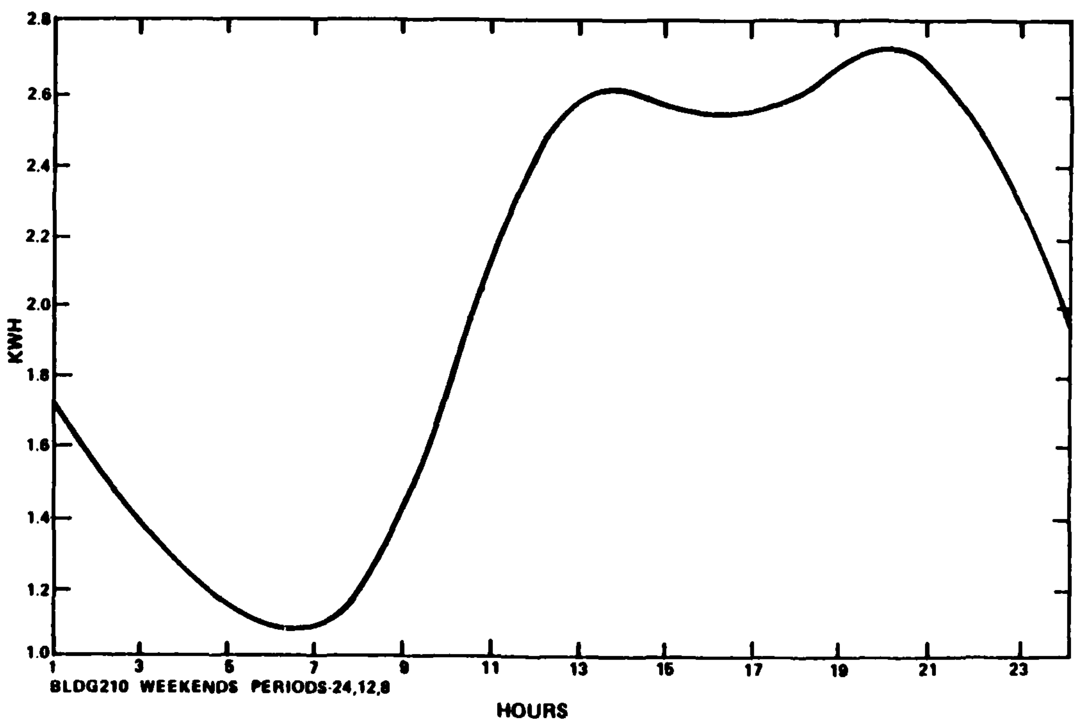
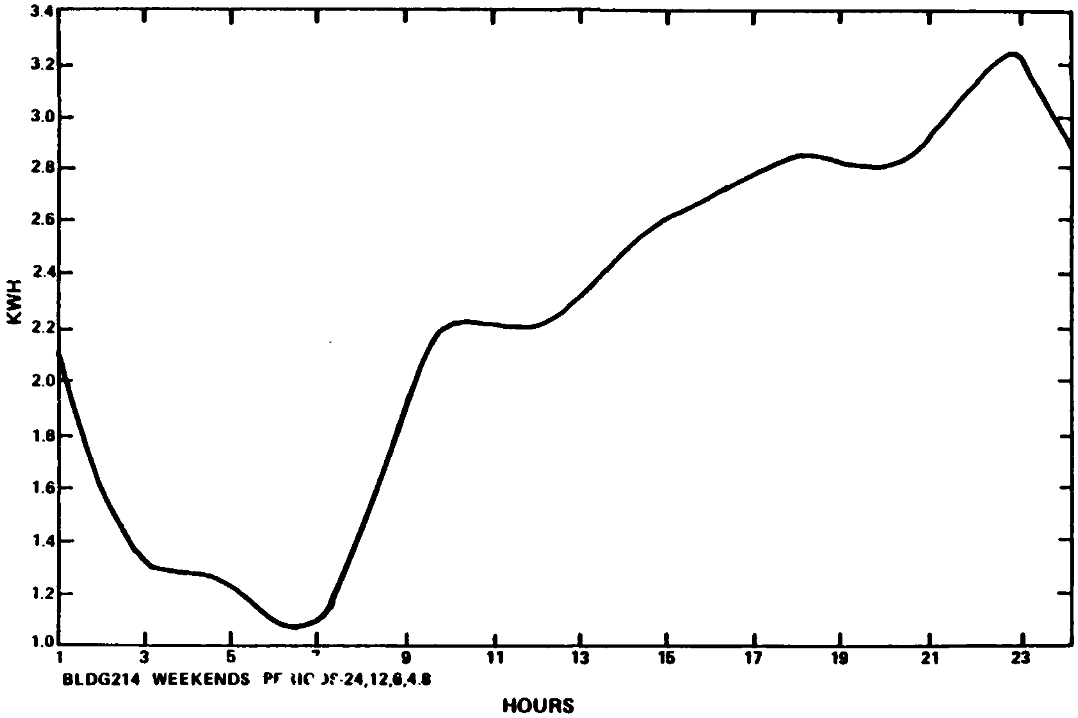


Figure 15. Time series characterization—family housing.



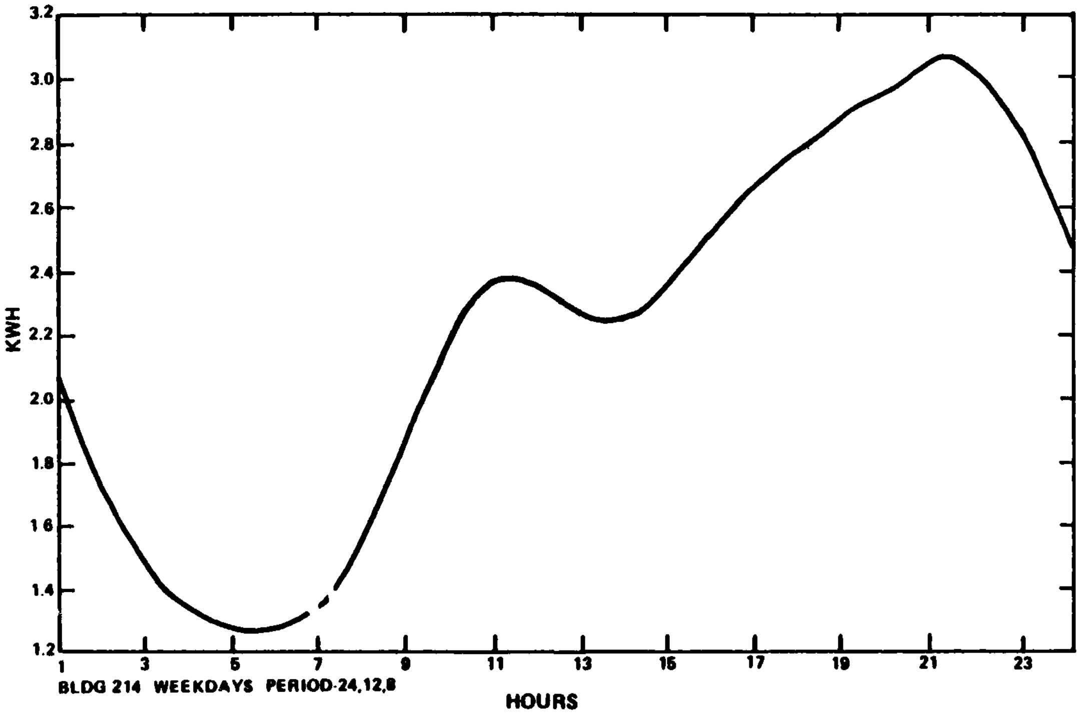
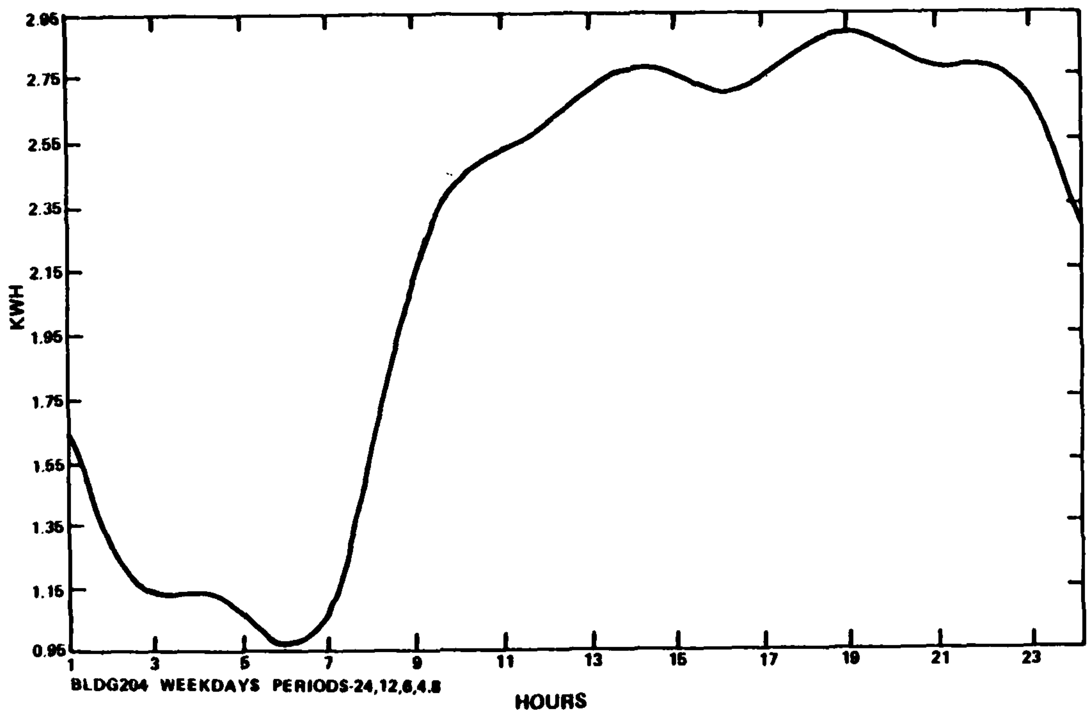


Figure 15. (Cont'd).



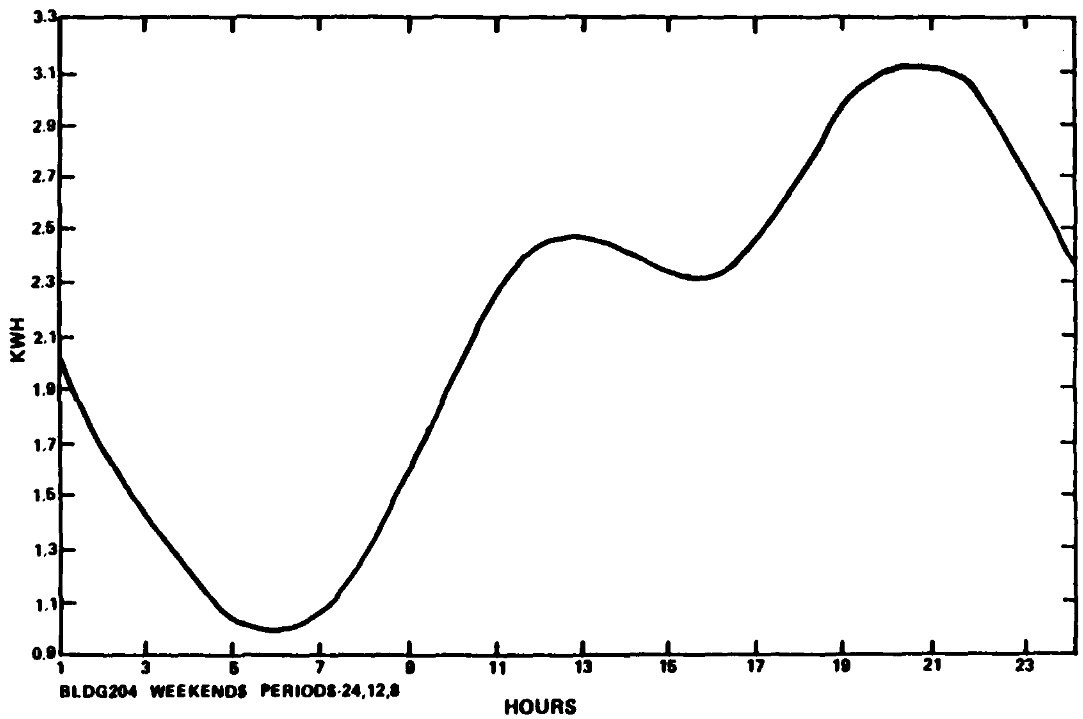
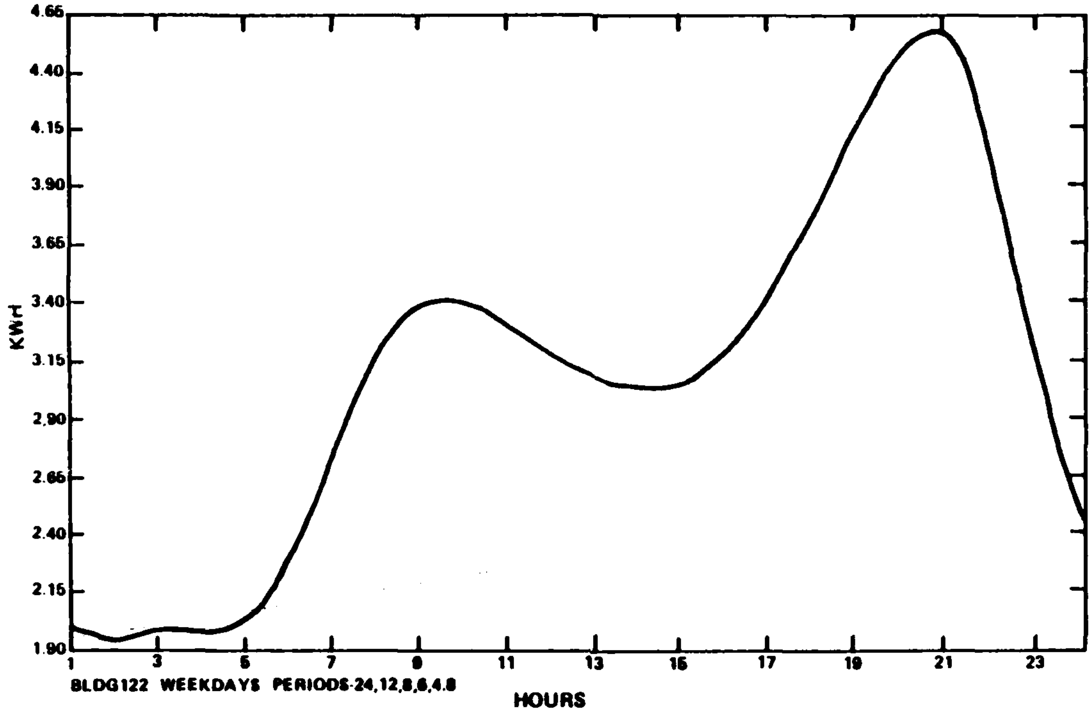


Figure 15. (Cont'd).



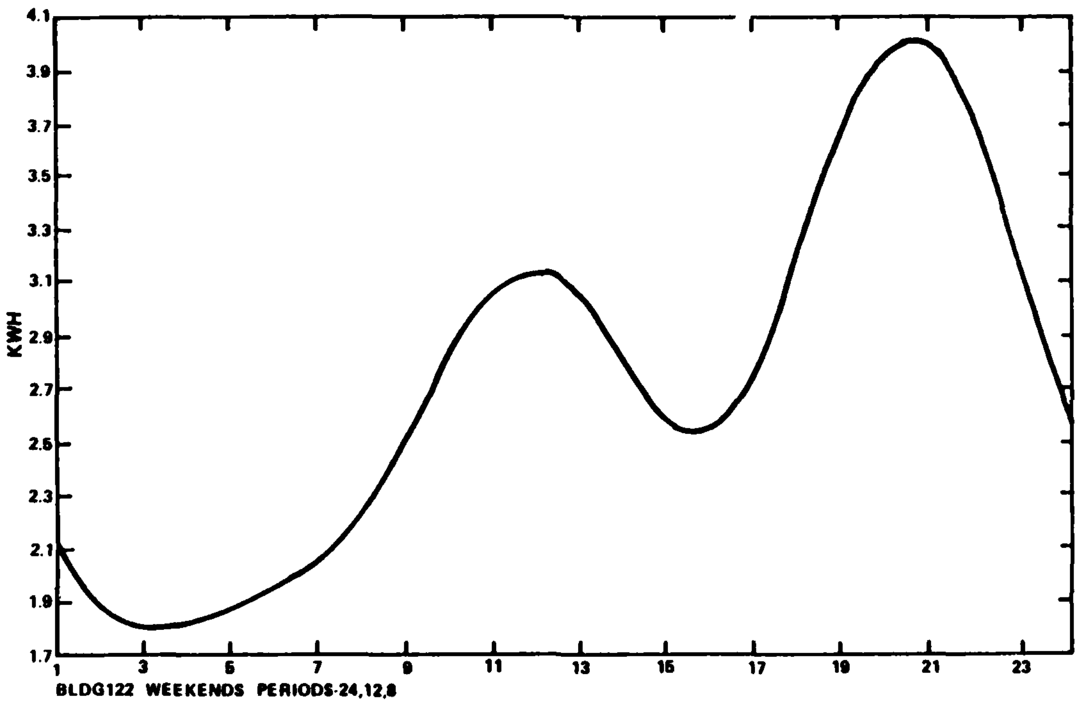
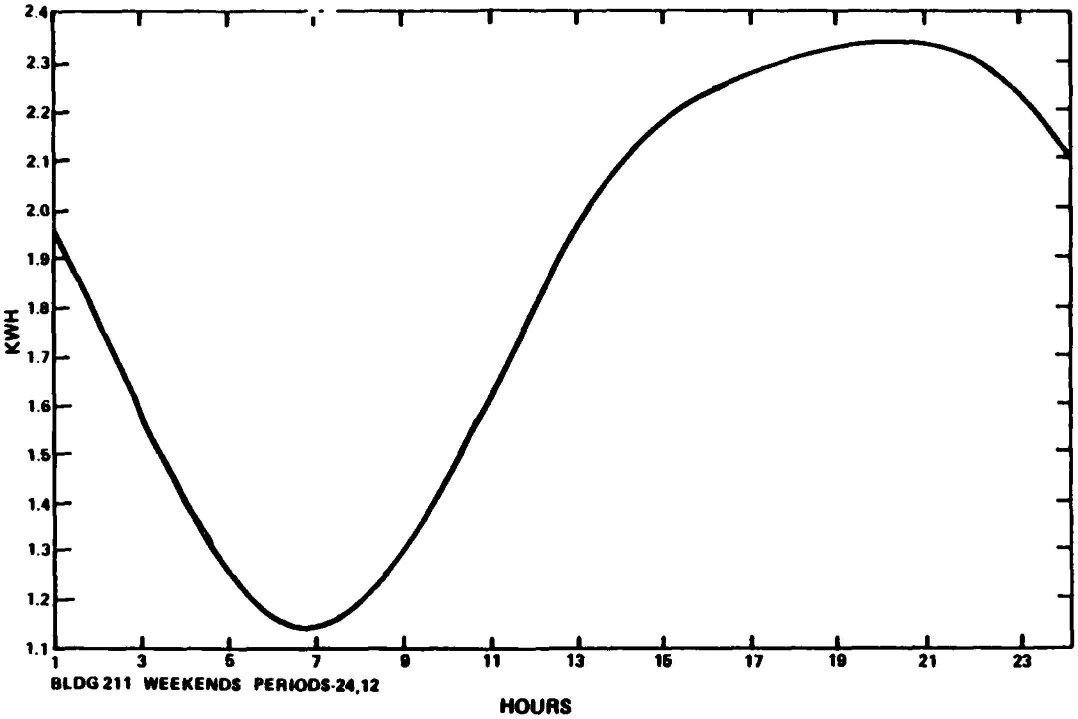


Figure 15. (Cont'd).



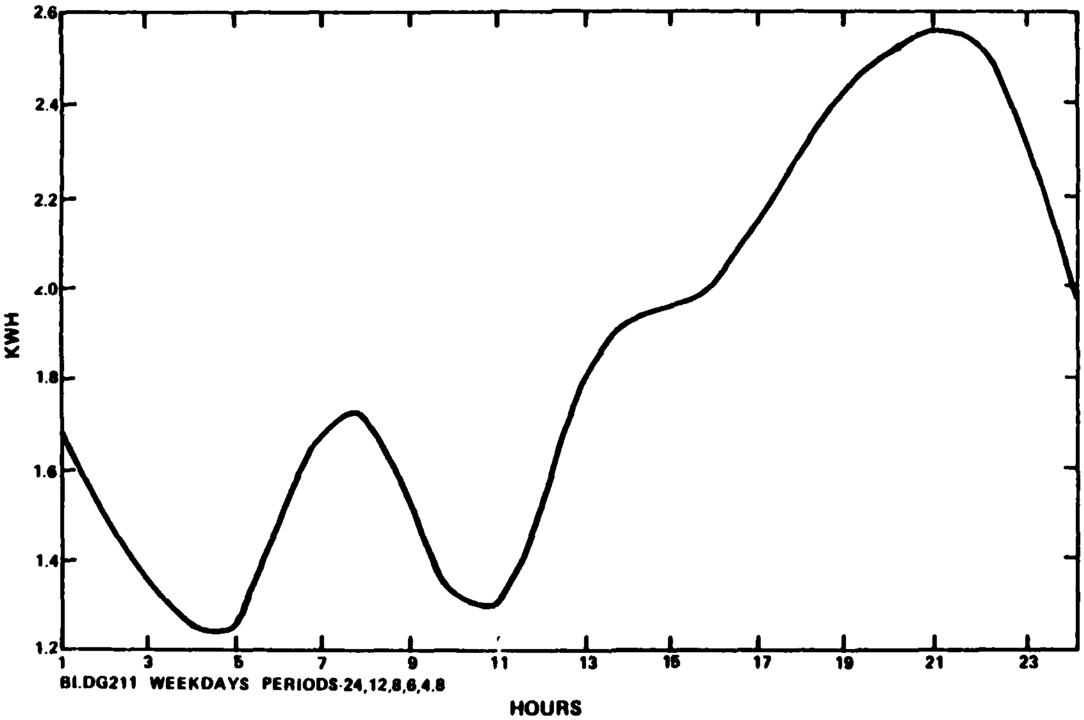
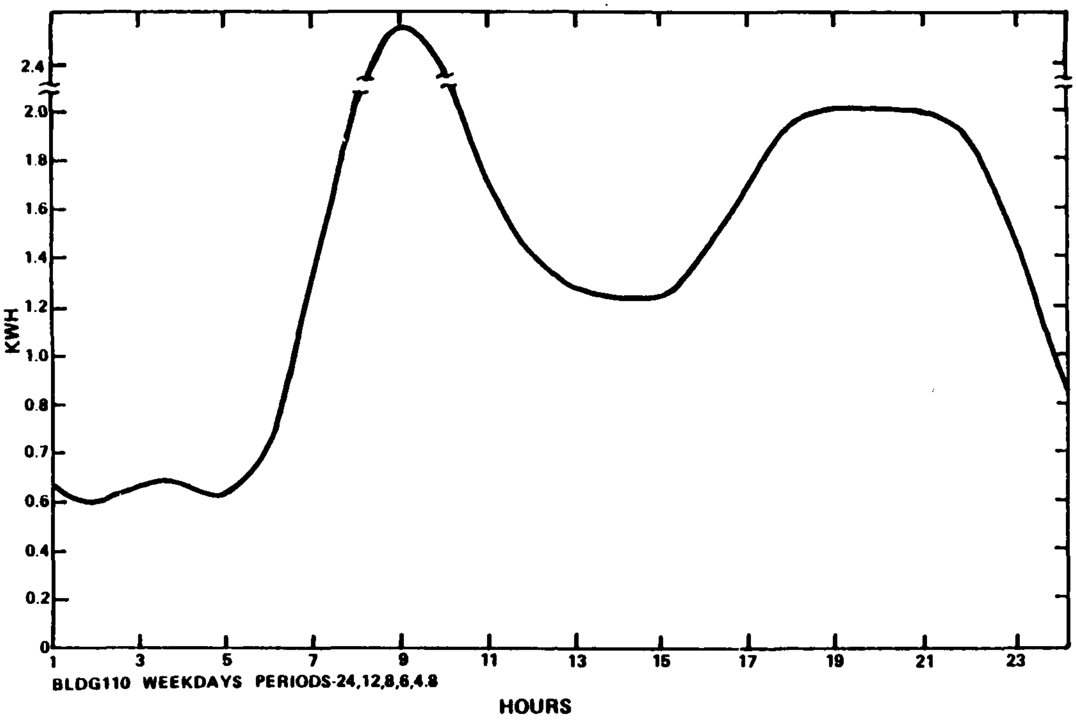


Figure 15. (Cont'd).



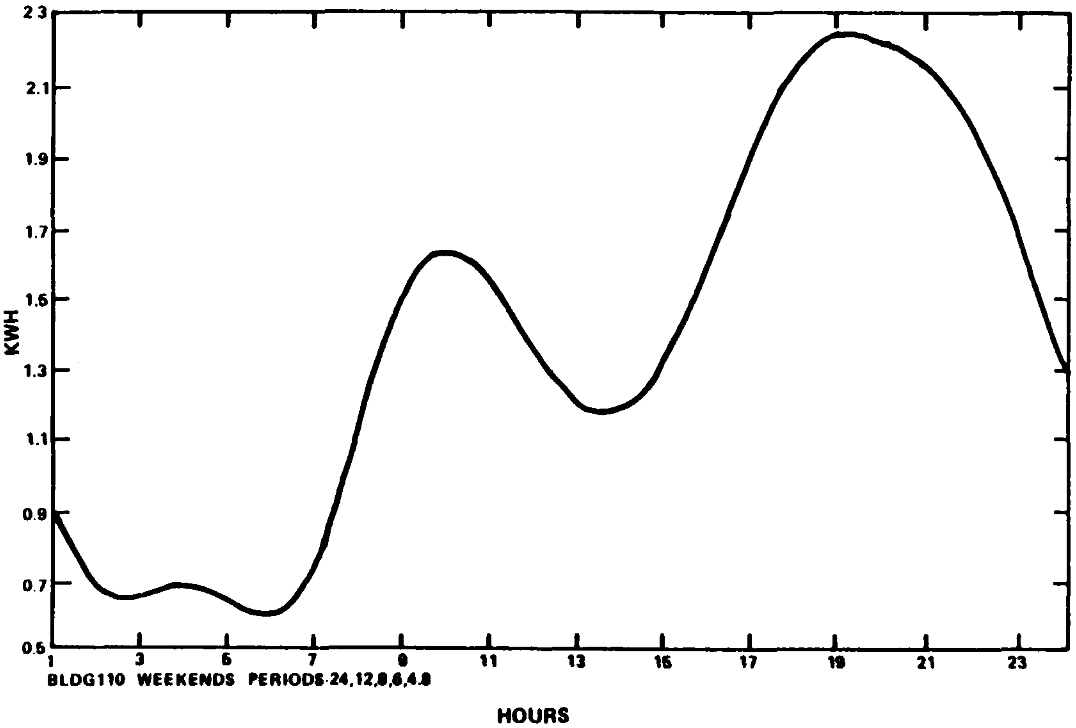
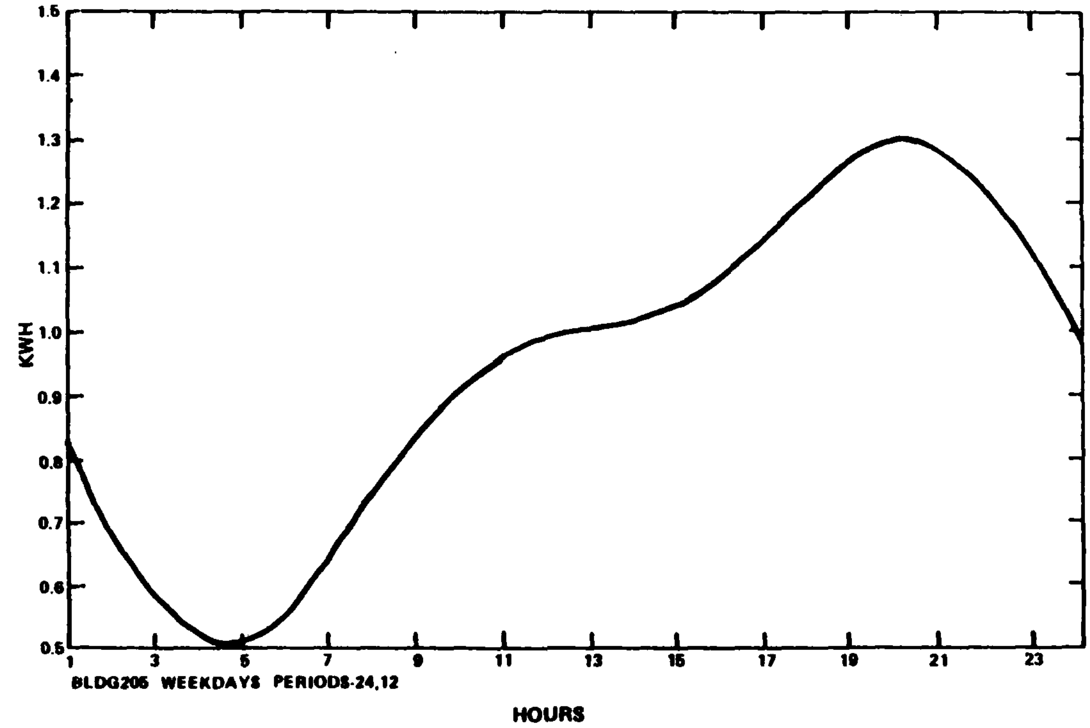


Figure 15. (Cont'd).



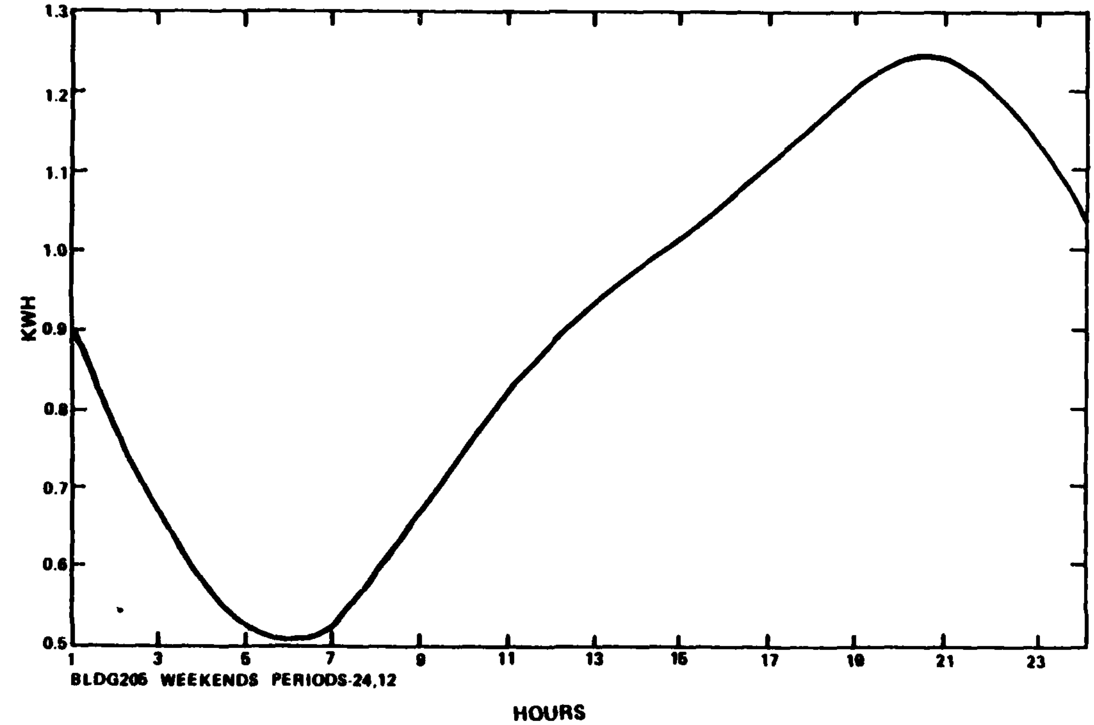
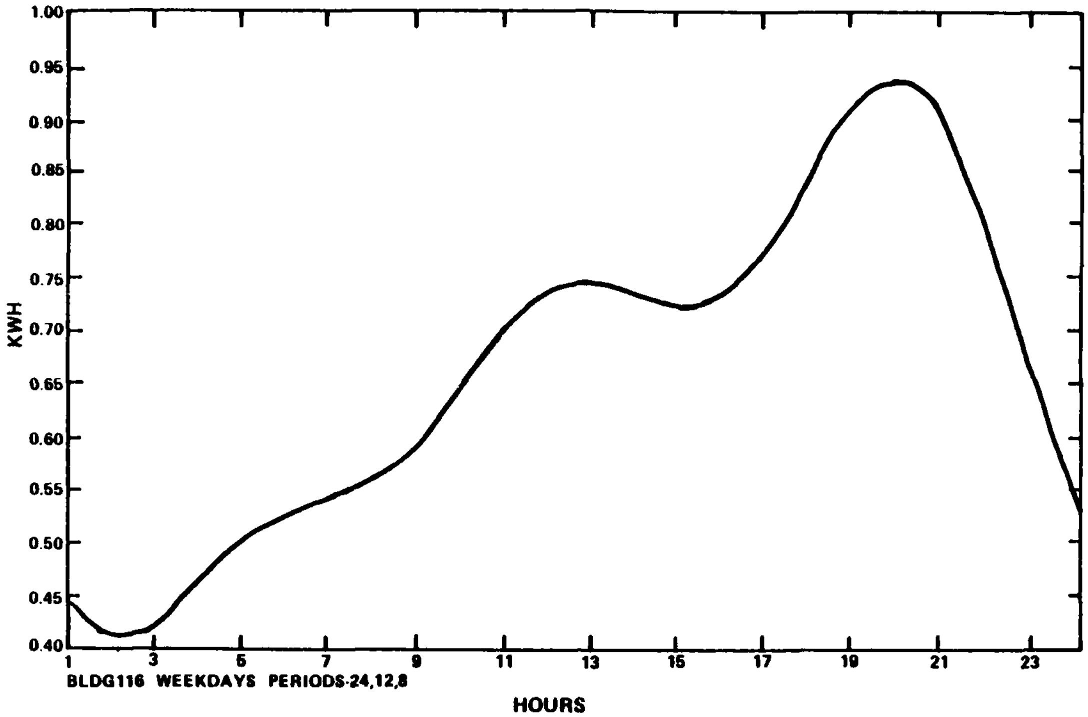


Figure 15. (Cont'd).



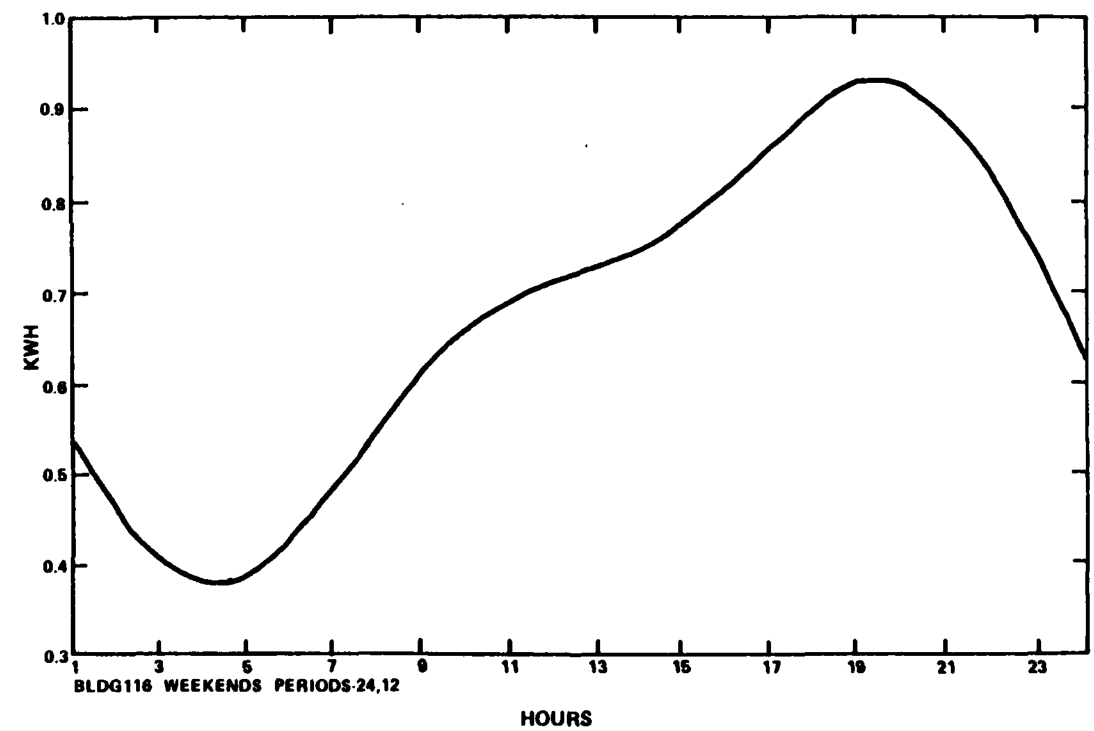


Figure 15. (Cont'd).

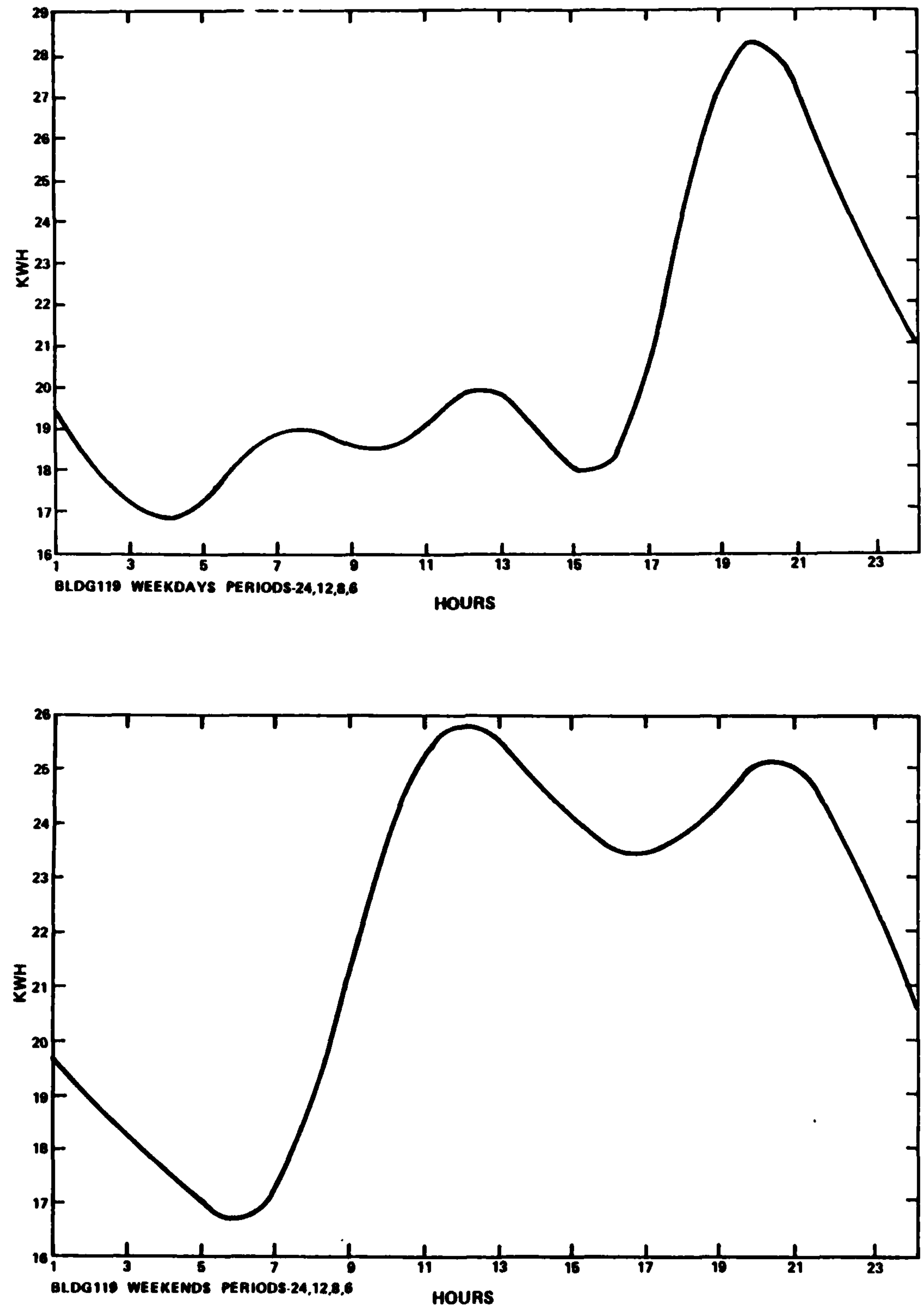
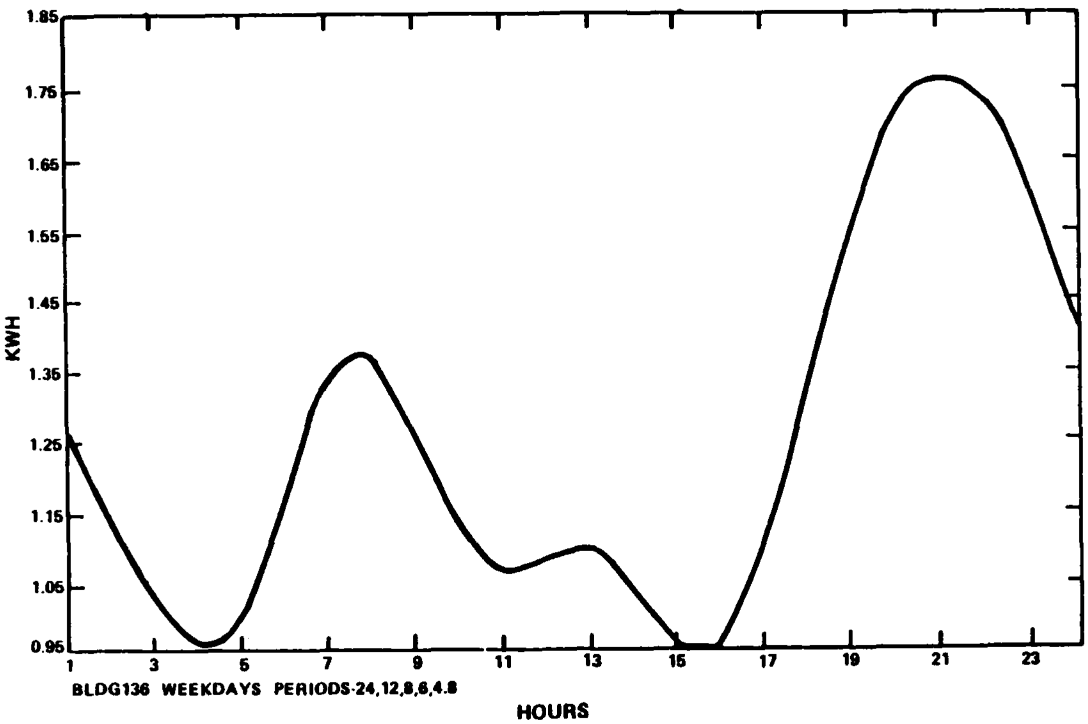


Figure 16. Time series characterization—troop housing.



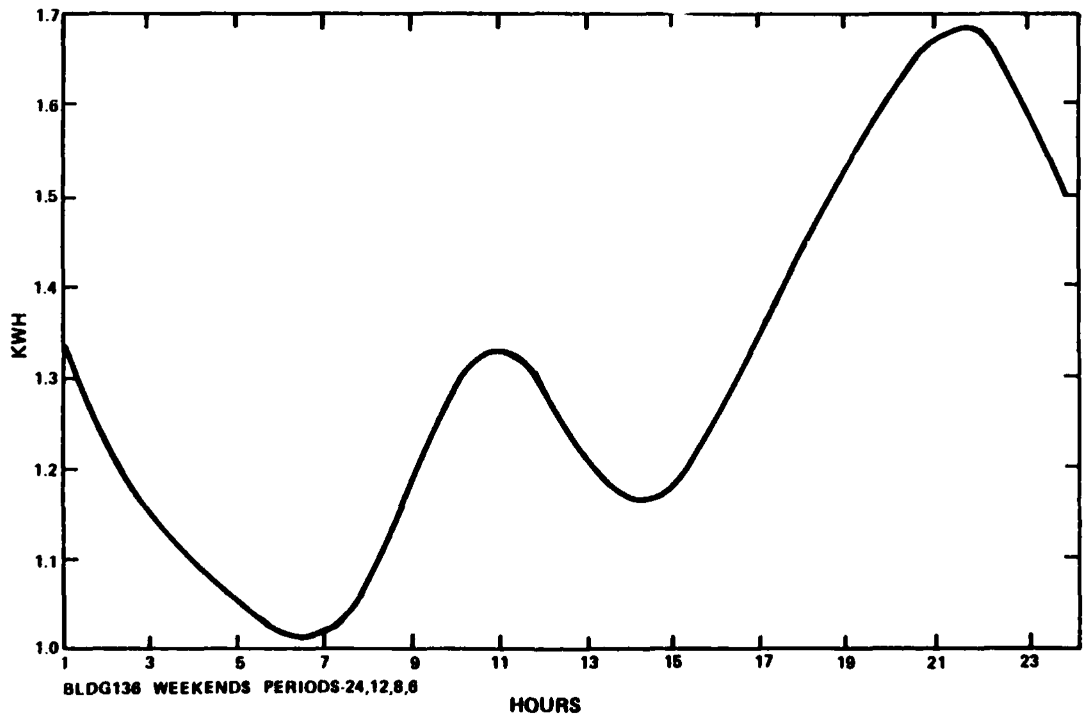
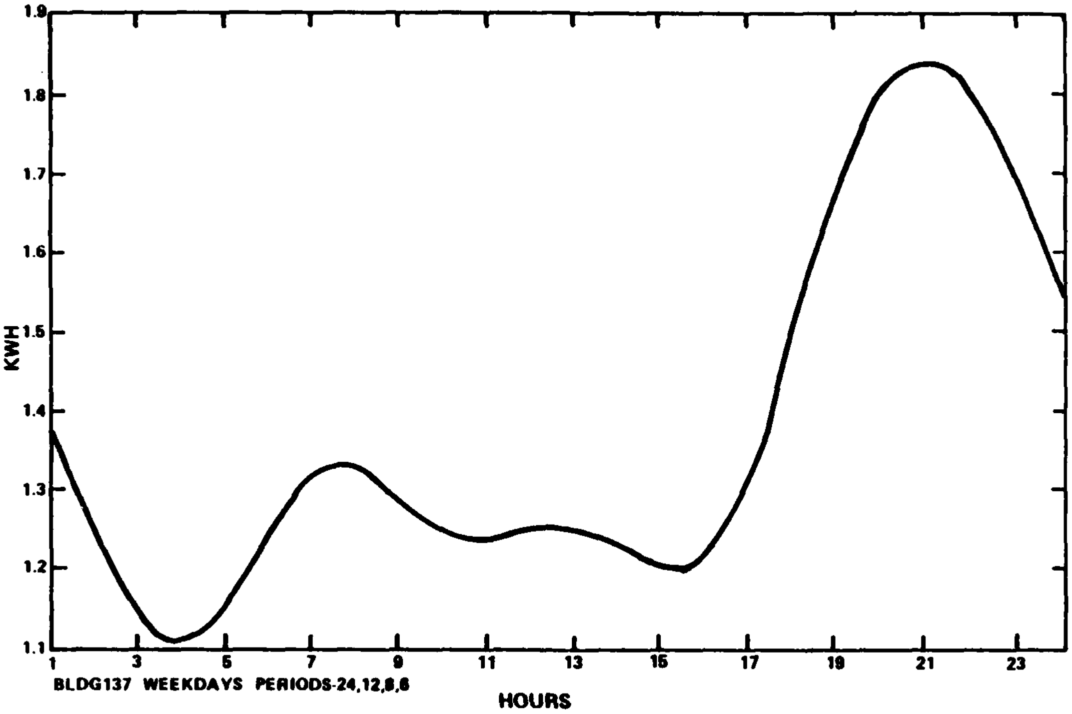


Figure 16. (Cont'd).



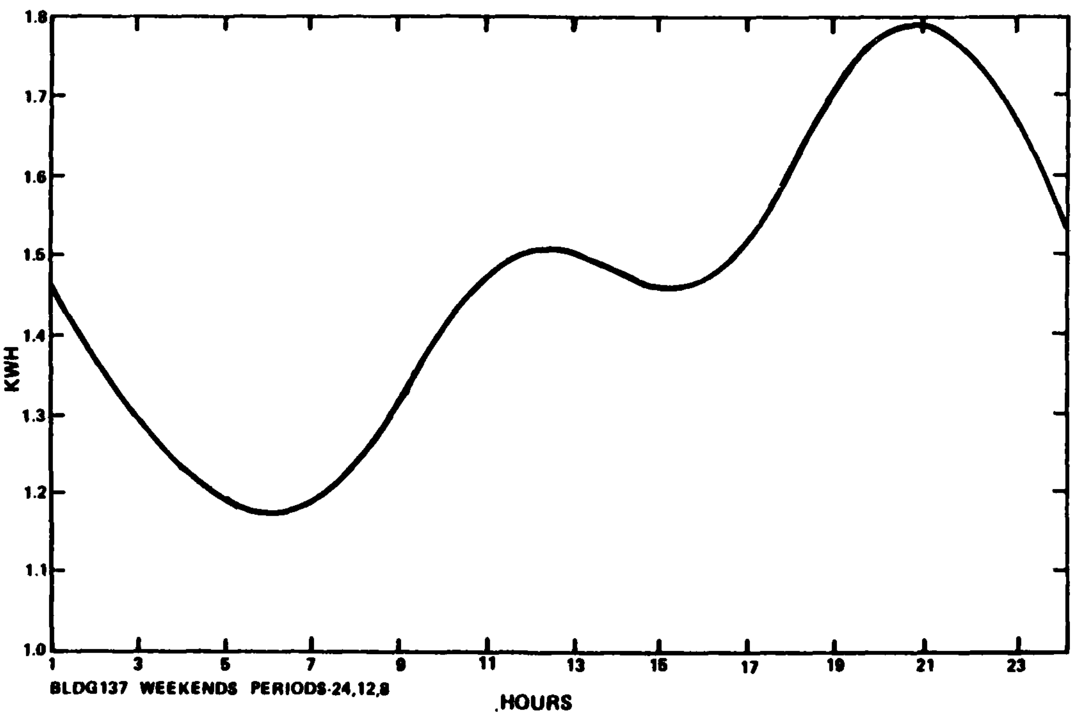
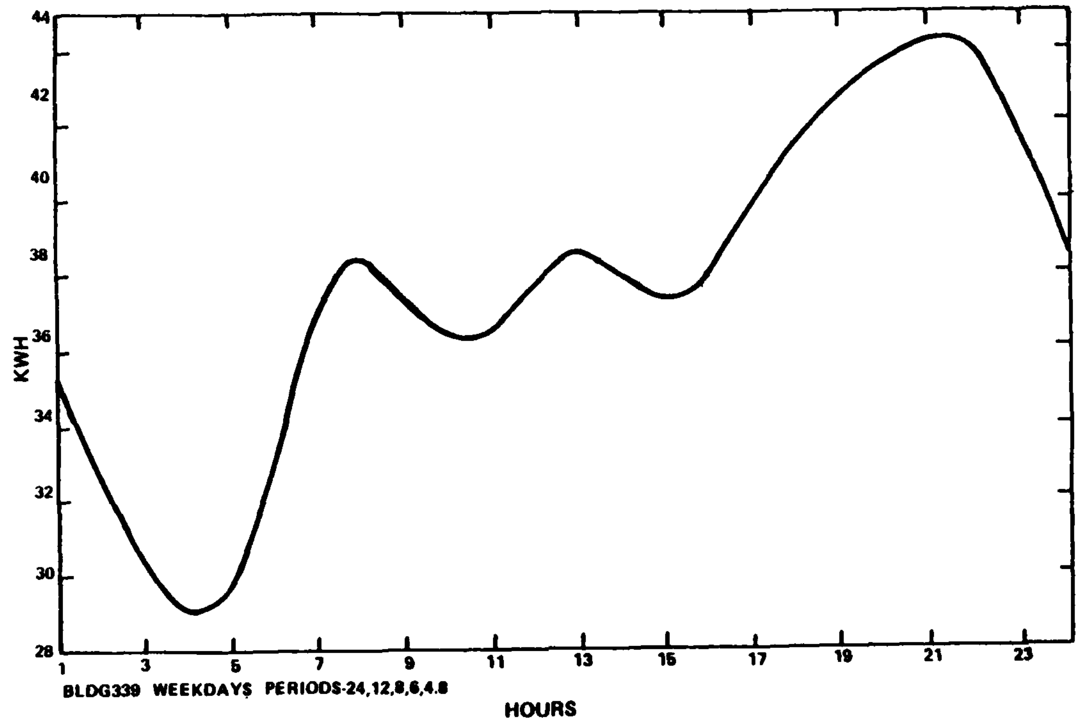


Figure 16. (Cont'd).



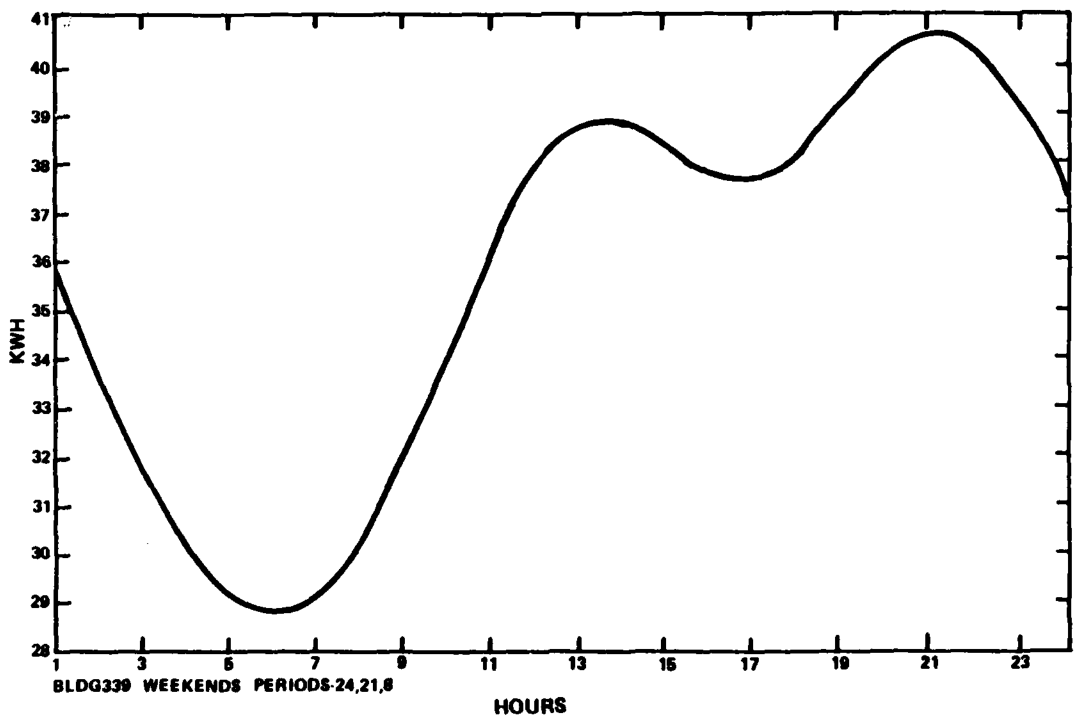
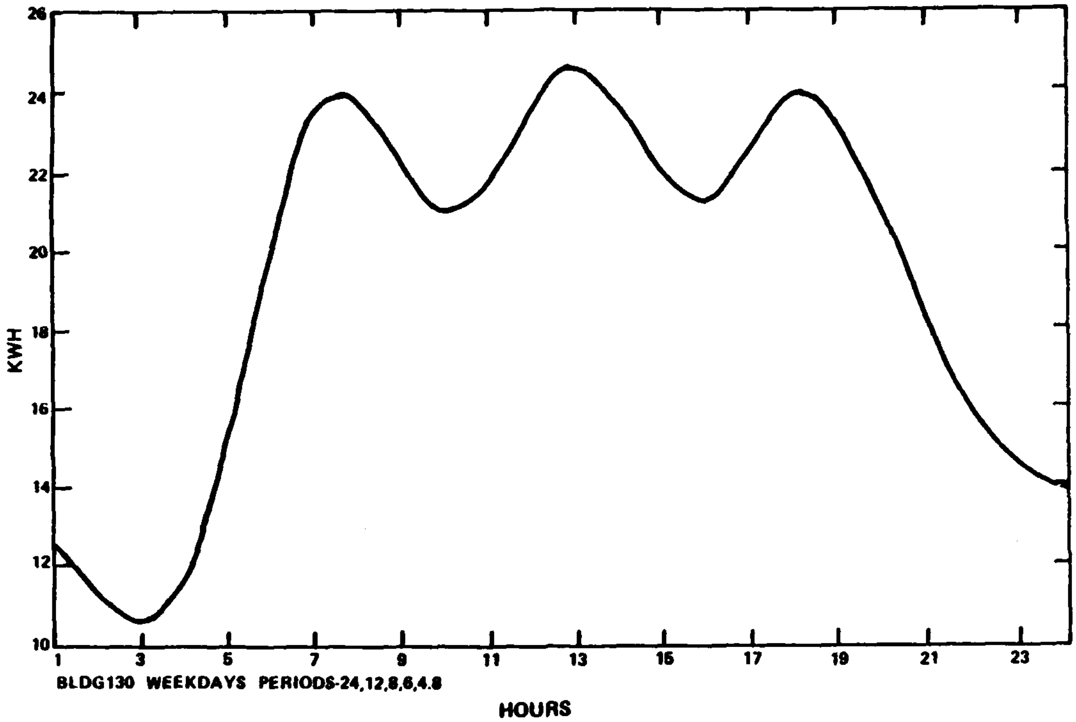


Figure 16. (Cont'd).



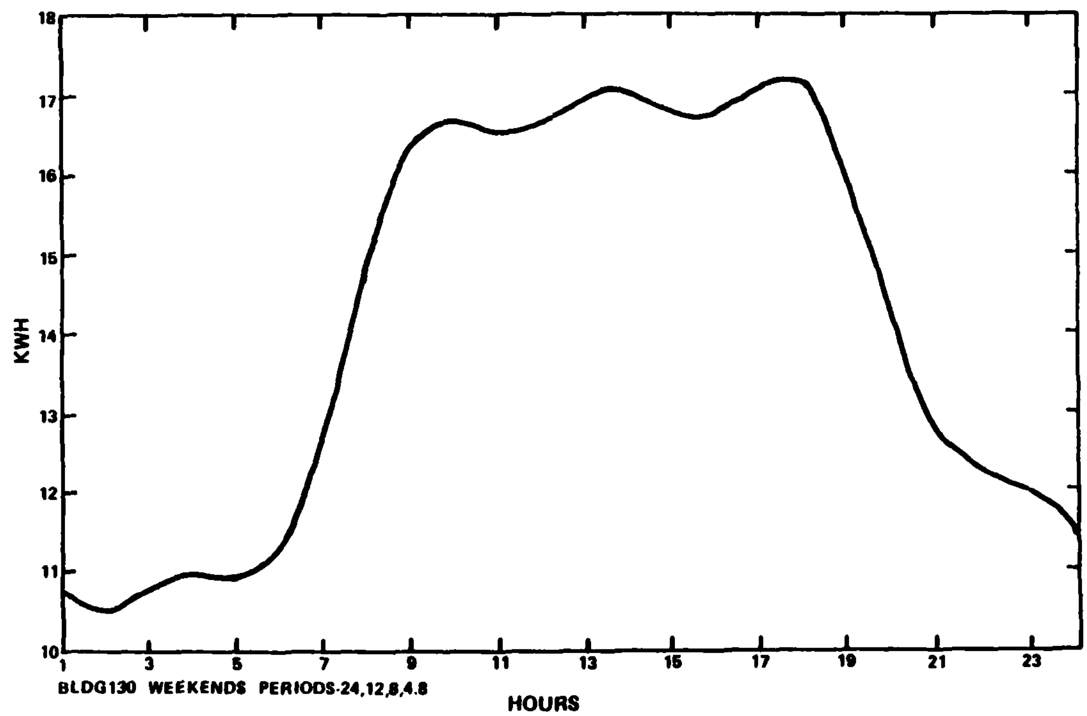
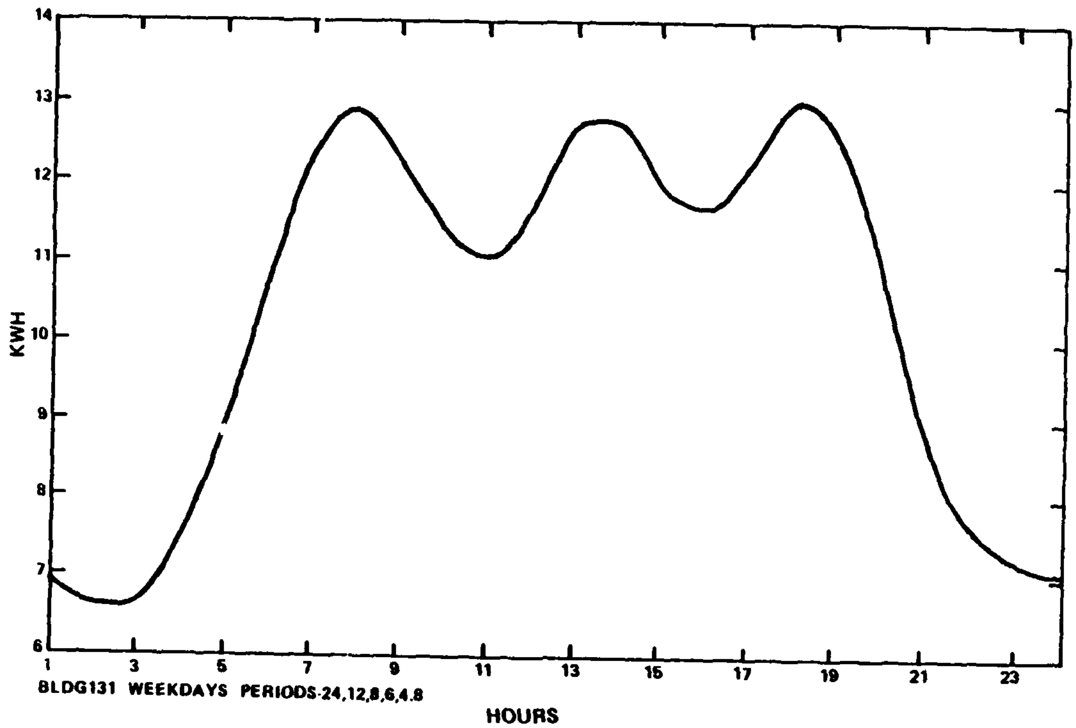


Figure 17. Time series characterization—dining facilities.



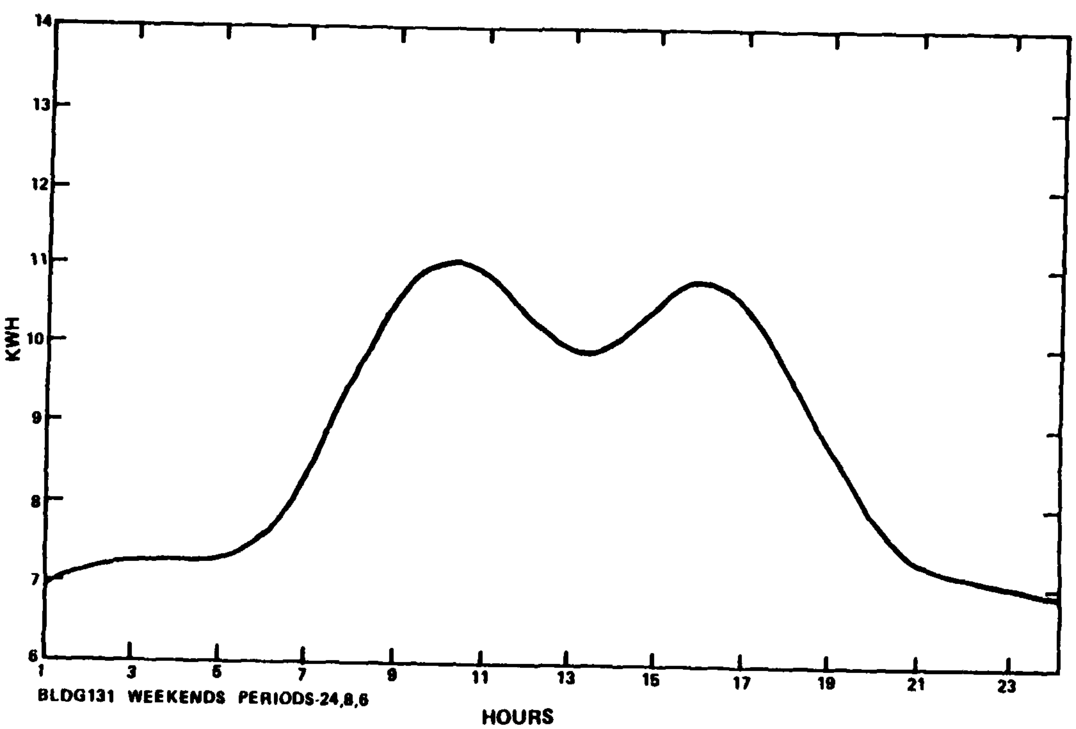
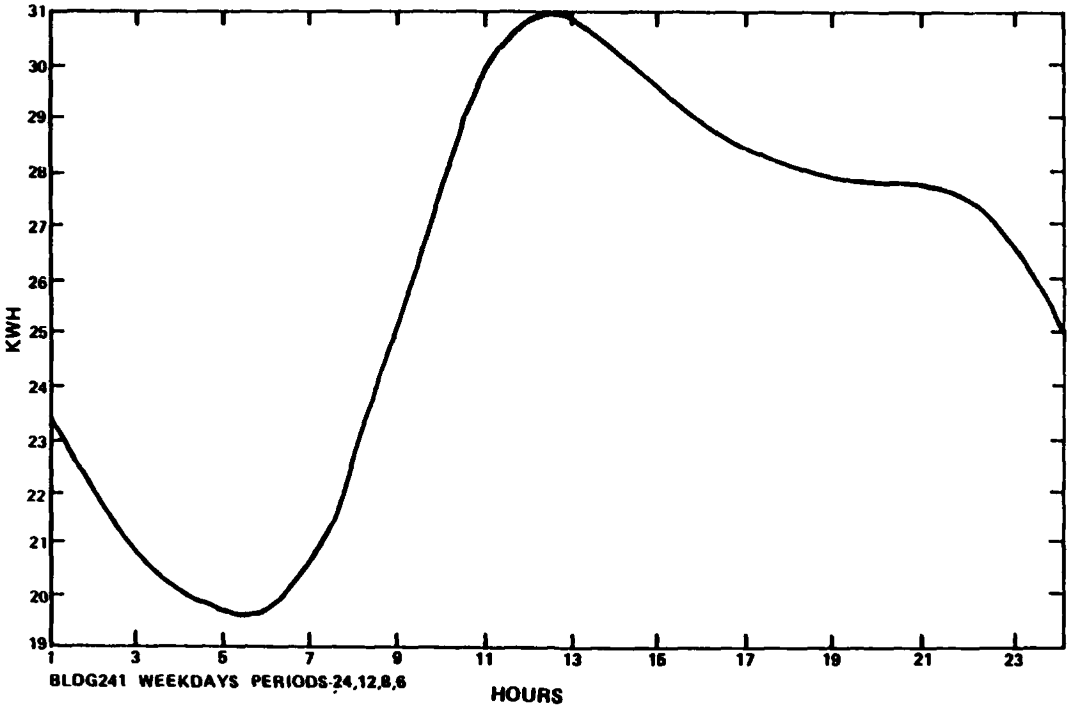


Figure 17. (Cont'd)



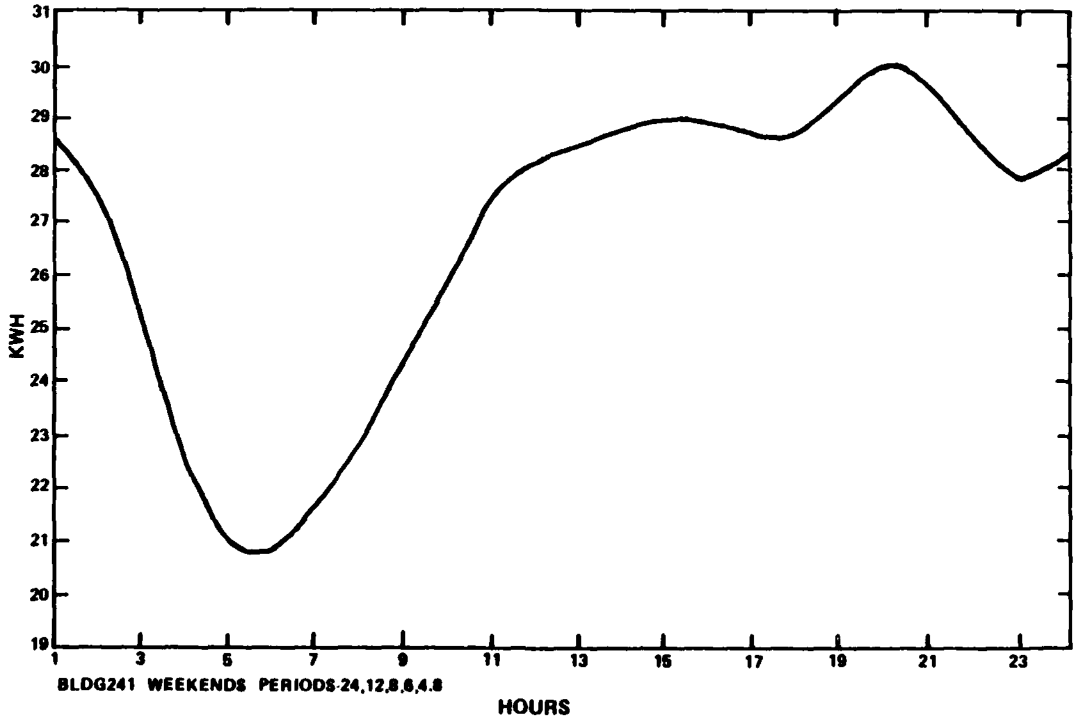
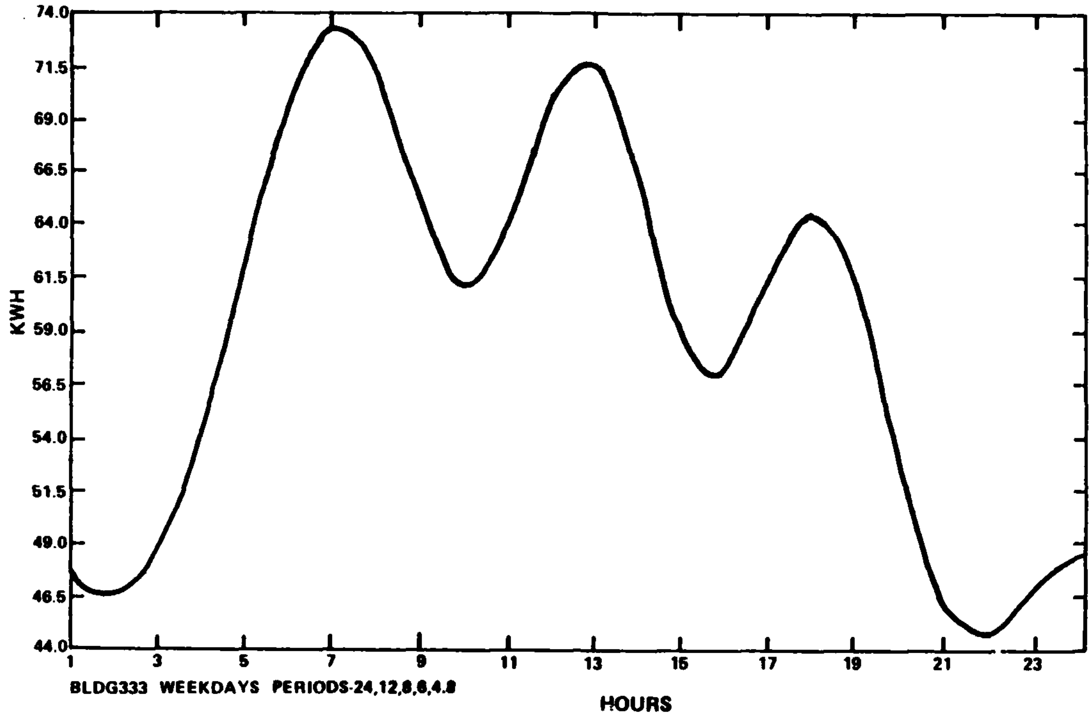


Figure 17. (Cont'd)



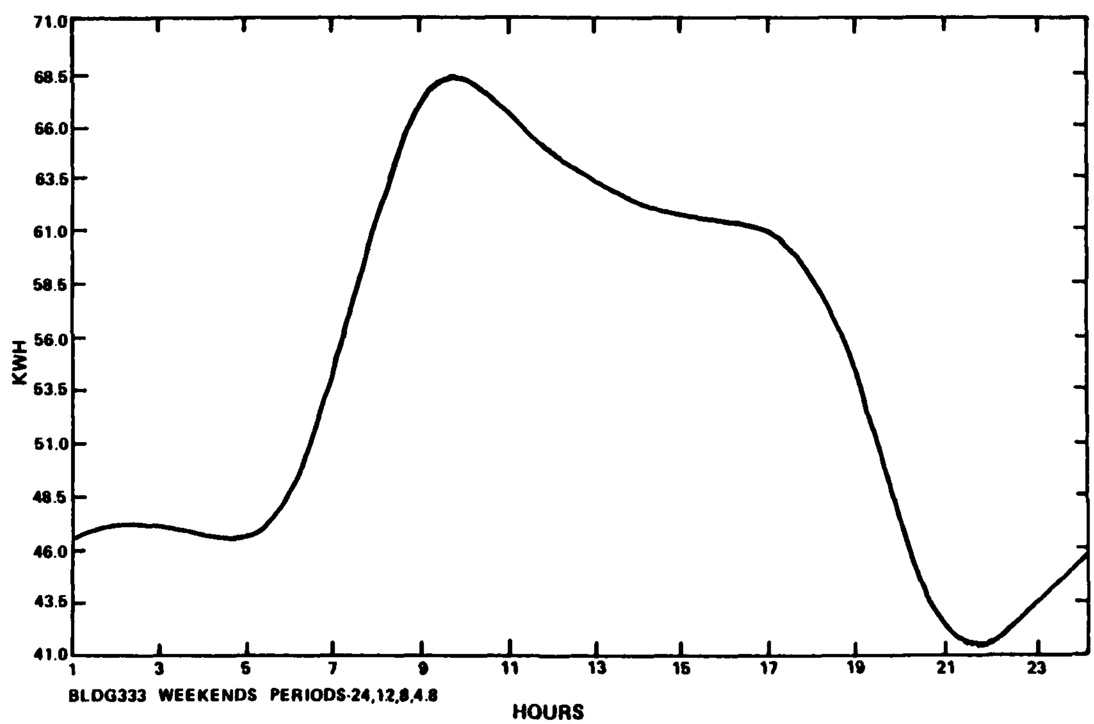
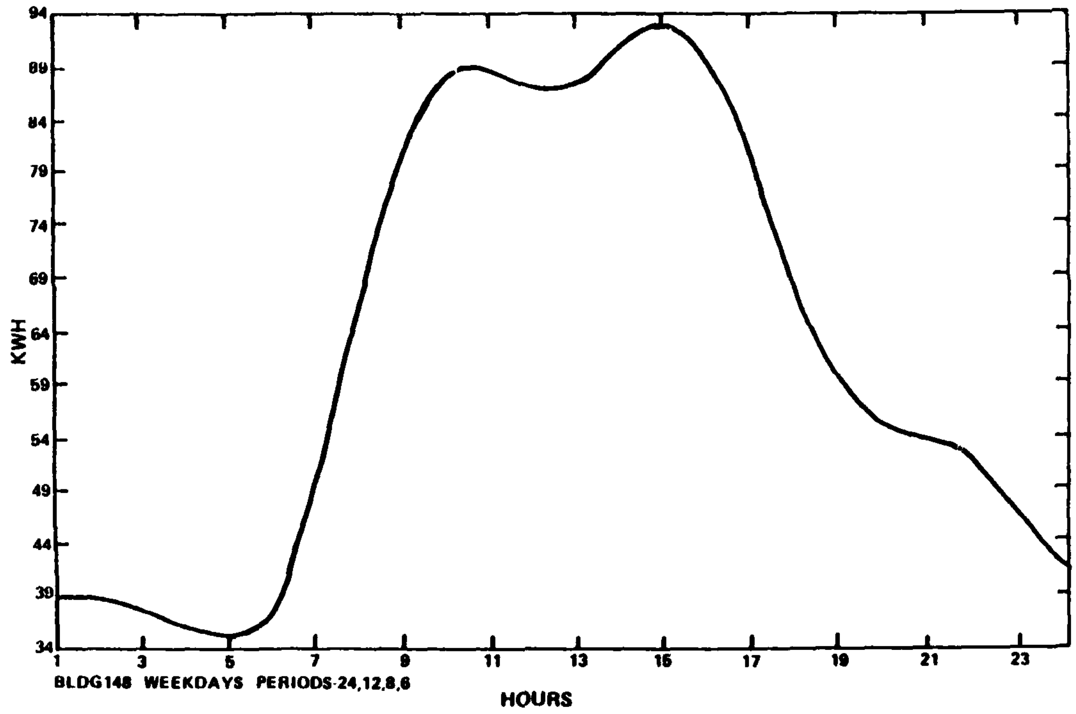


Figure 17. (Cont'd)



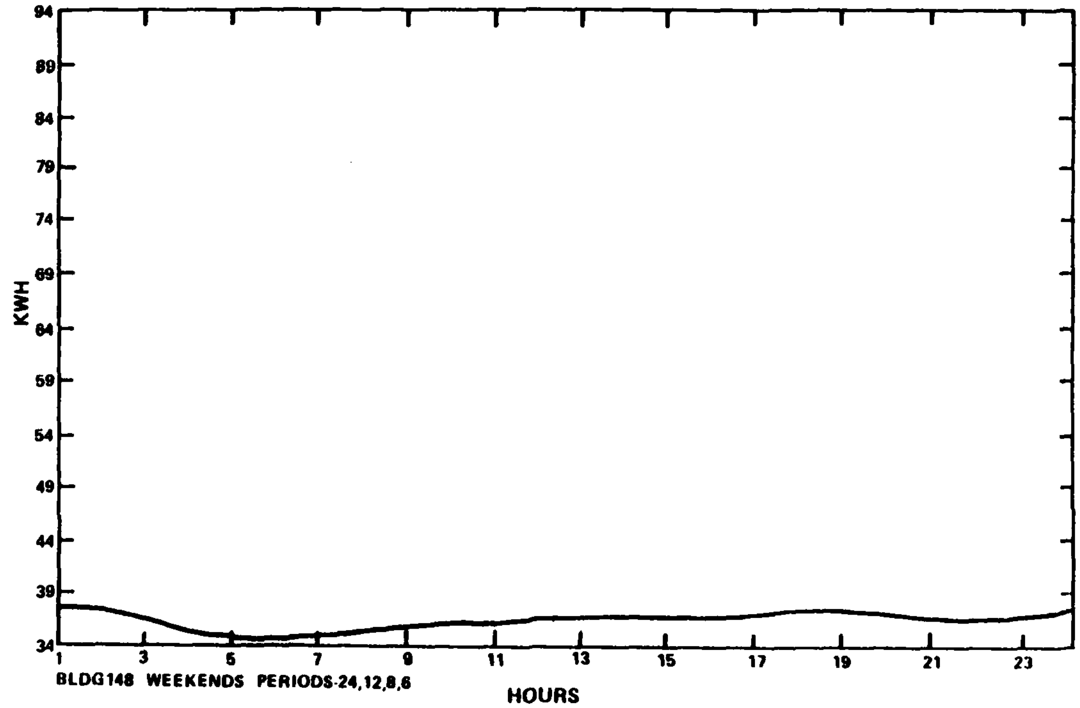
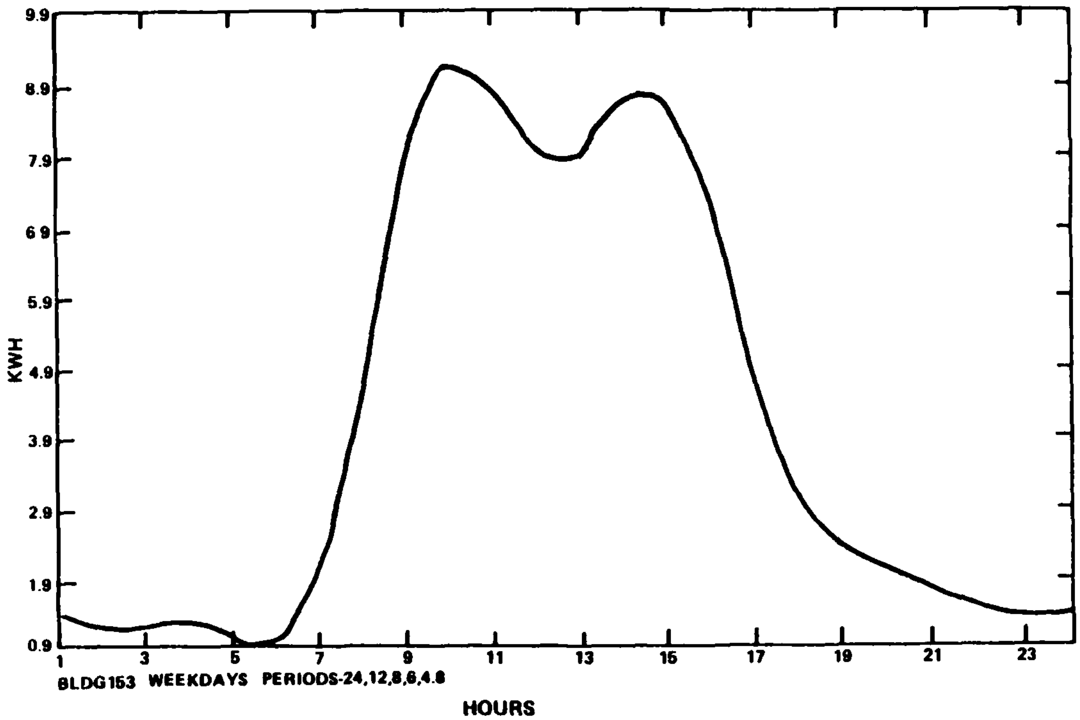


Figure 18. Time series characterization—administration building.



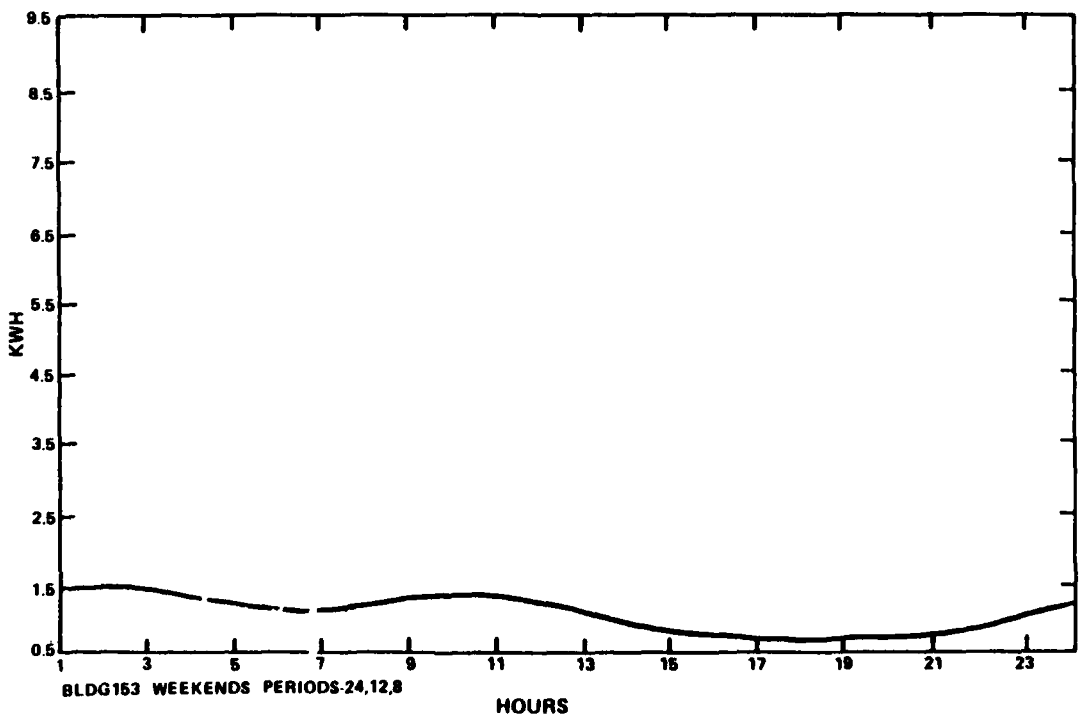
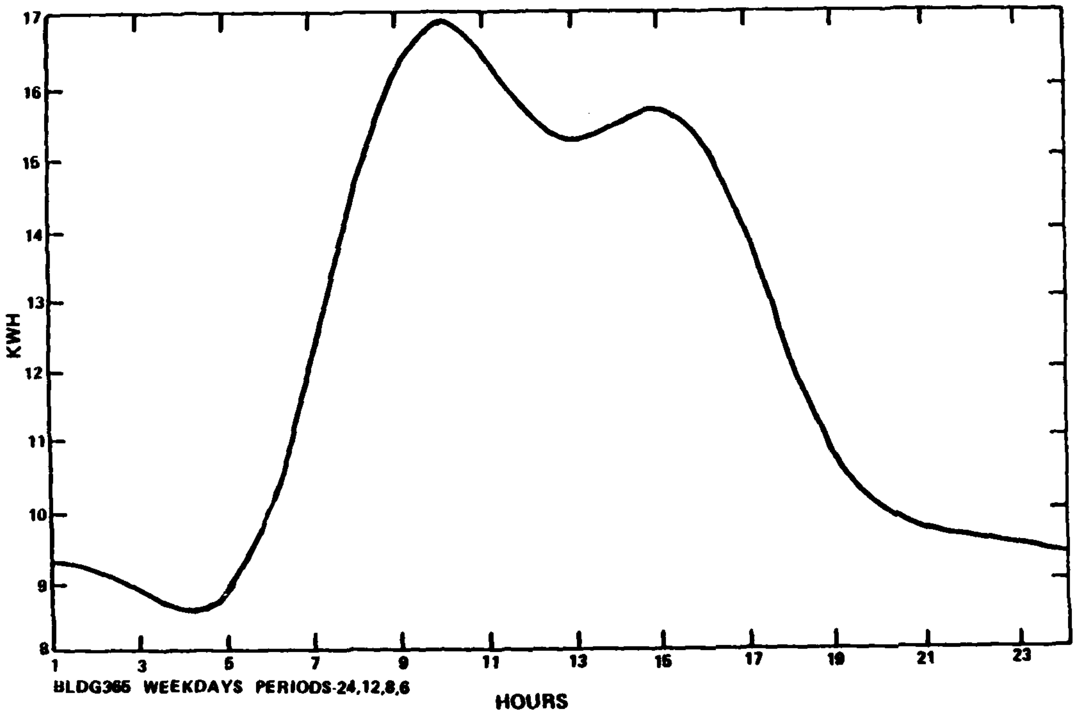


Figure 18. (Cont'd)



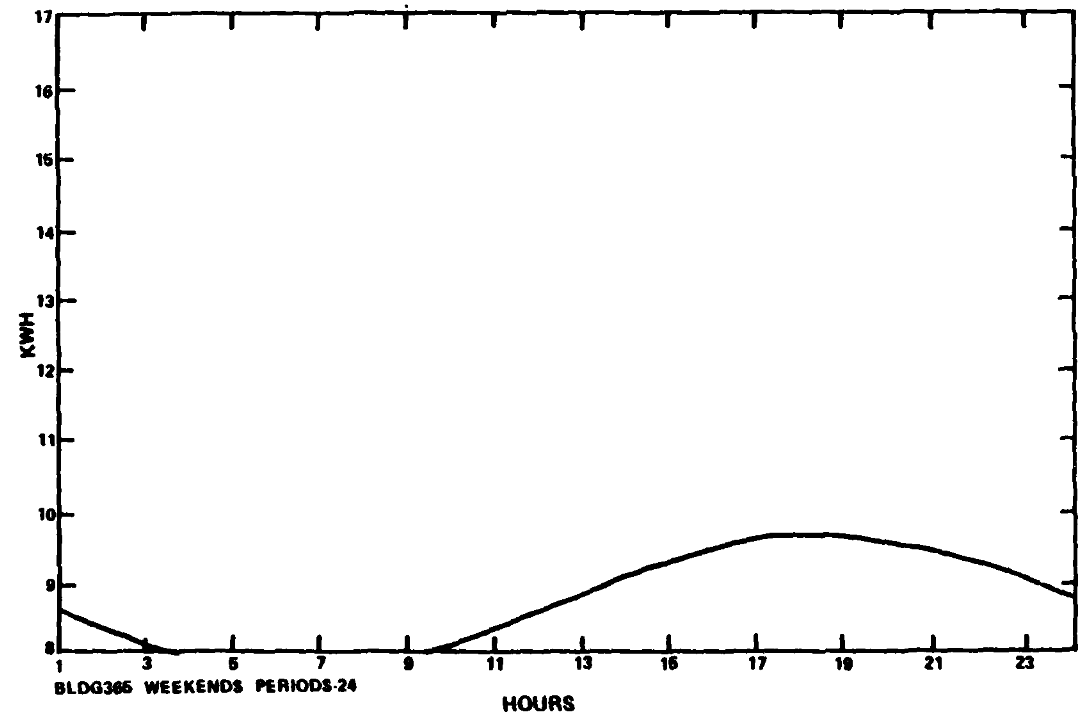
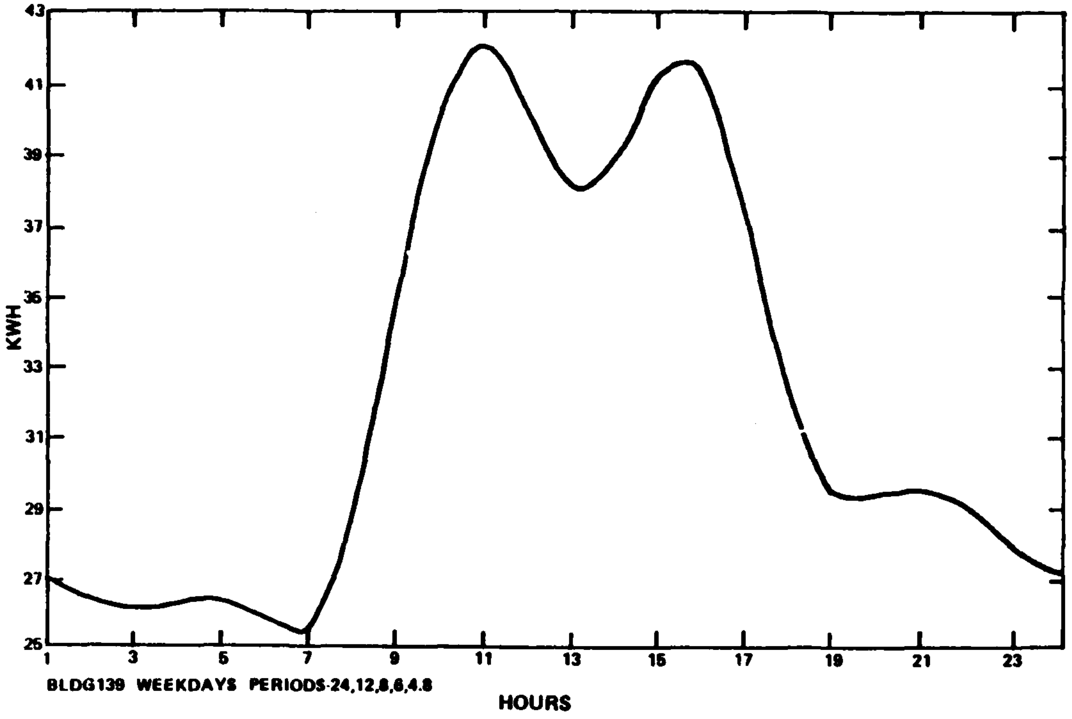


Figure 18. (Cont'd)



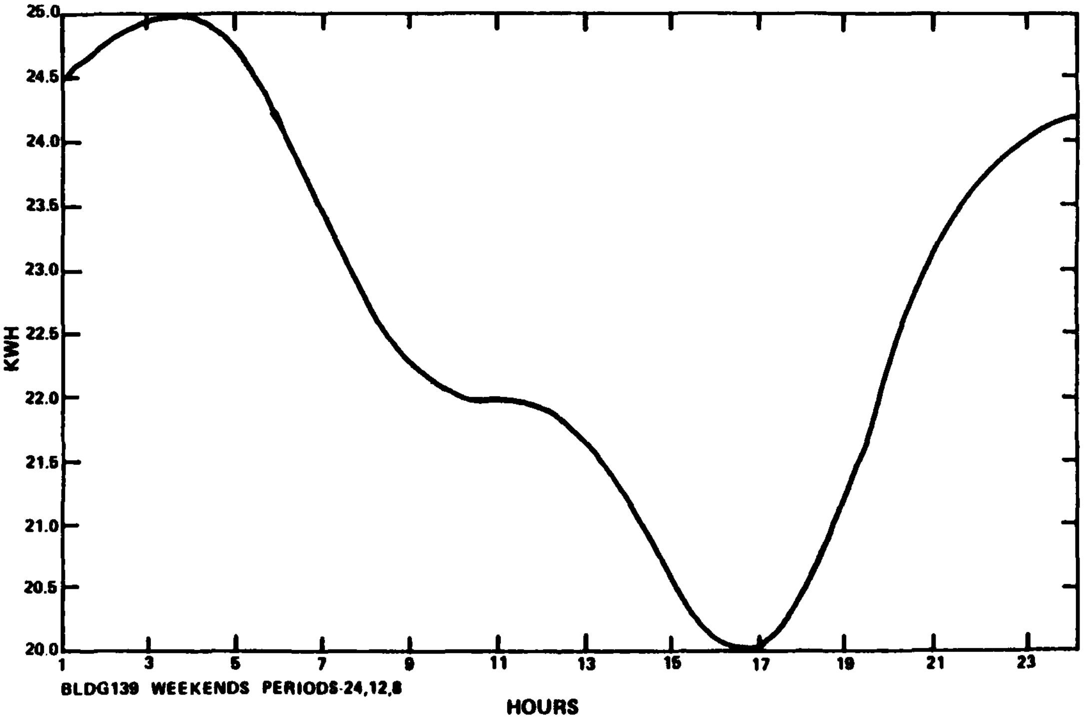
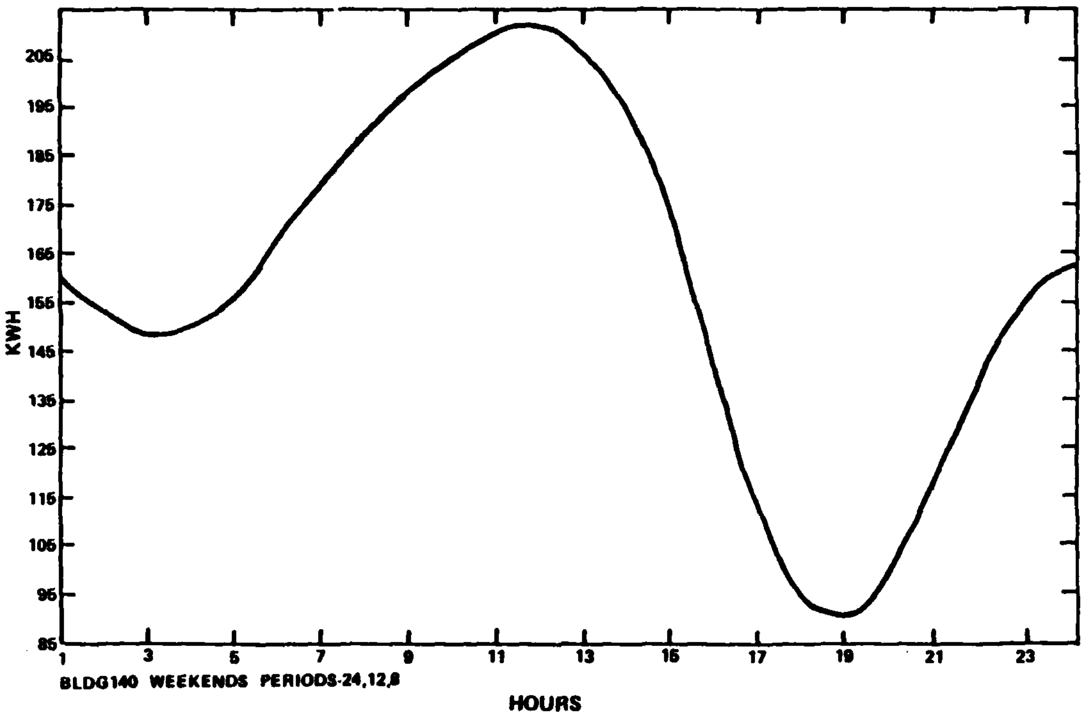


Figure 19. Time series characterization—maintenance facilities.



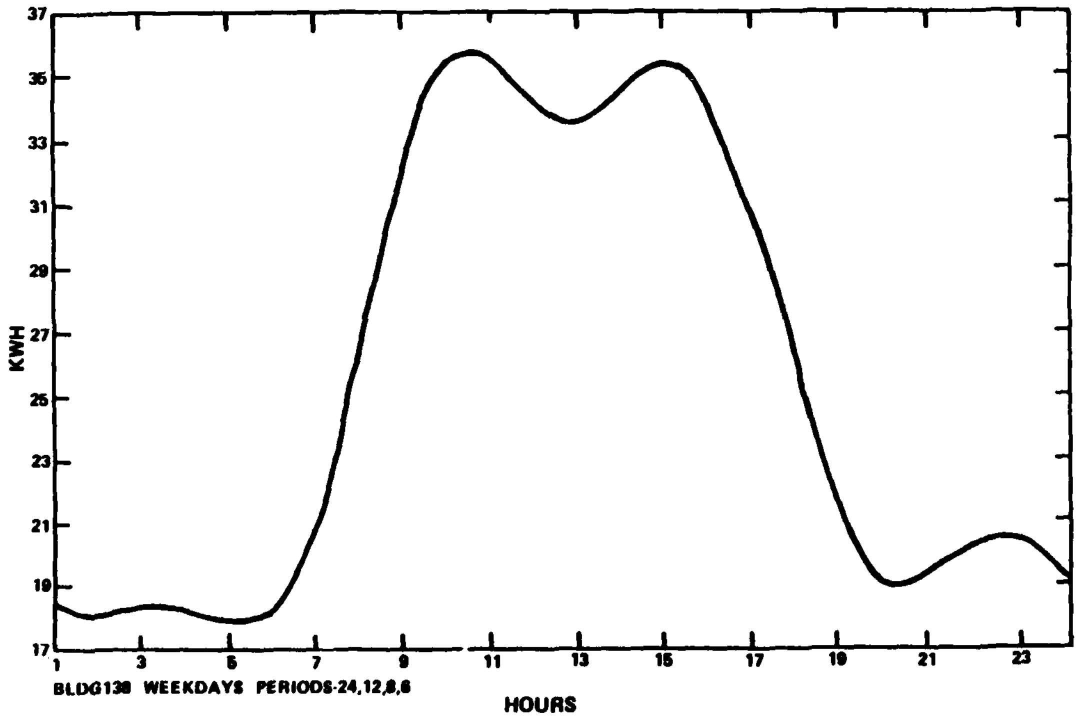
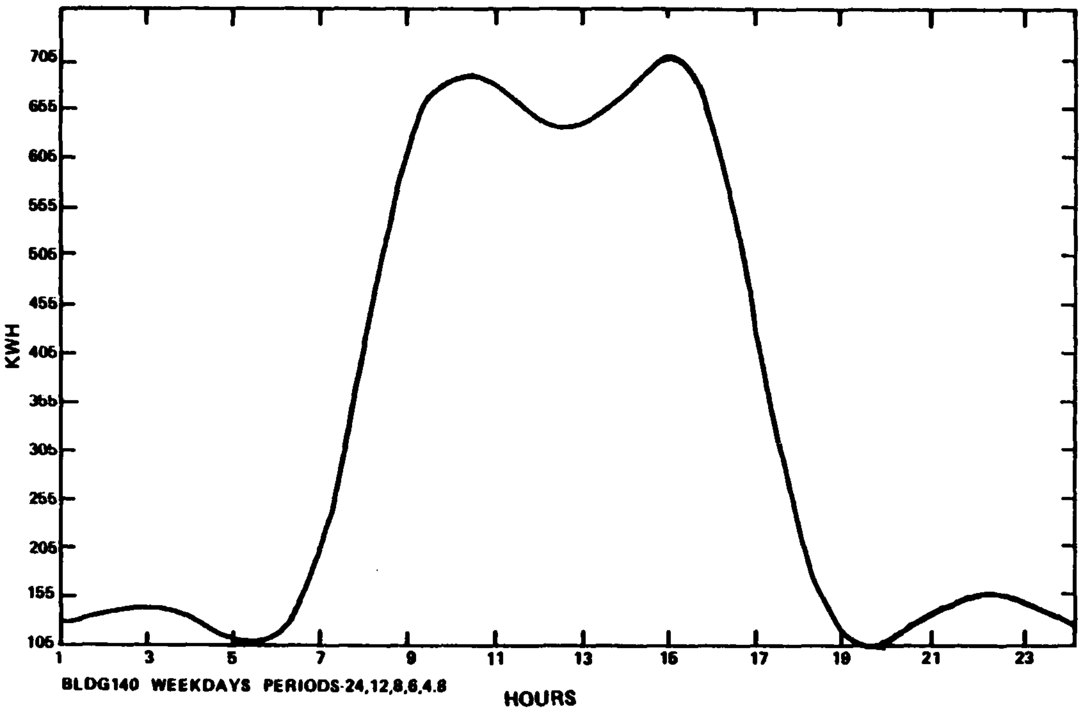


Figure 19. (Cont'd)



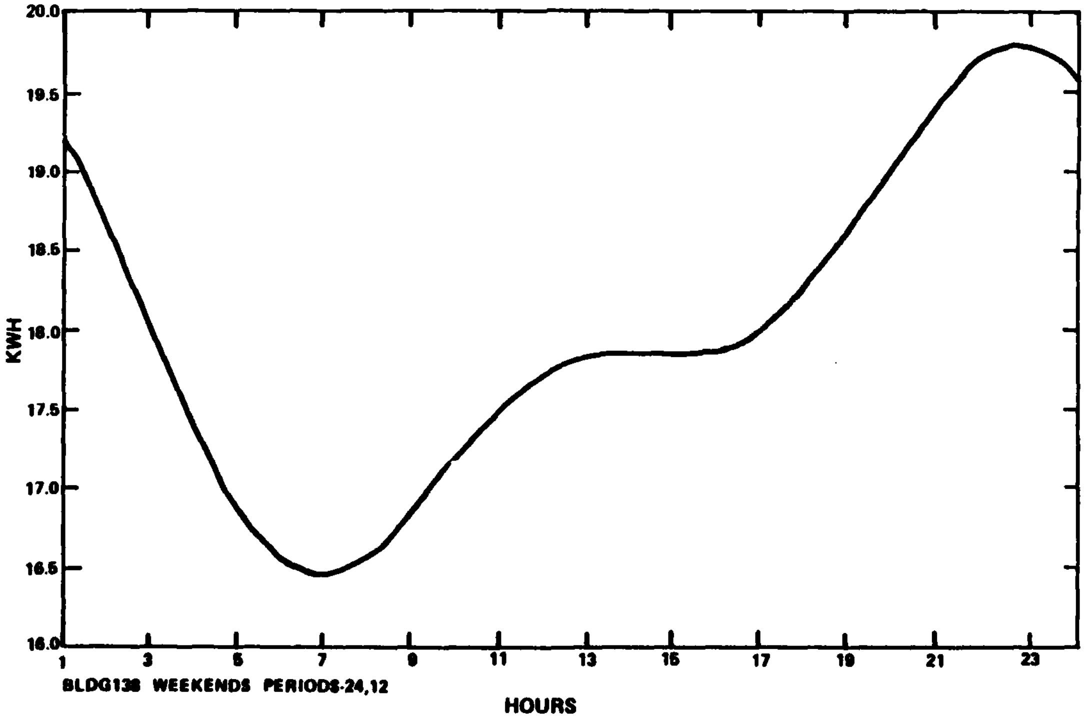


Figure 19. (Cont'd)

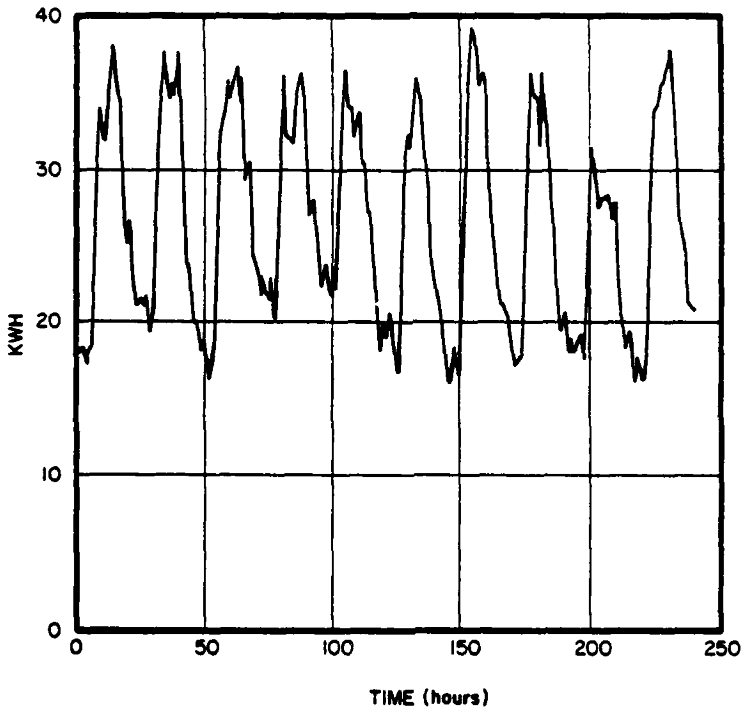


Figure 20. Actual energy consumption.

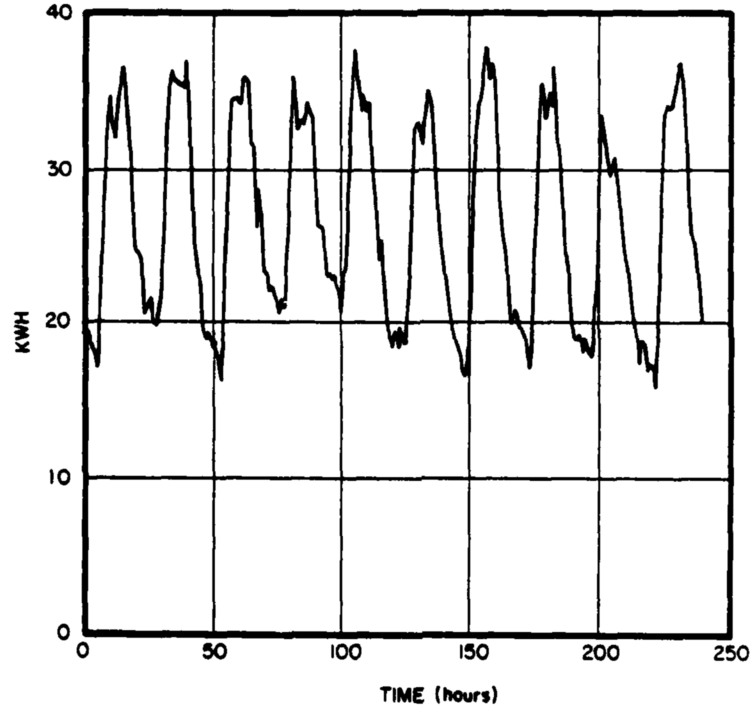


Figure 21. Model predictions of actual energy consumption.

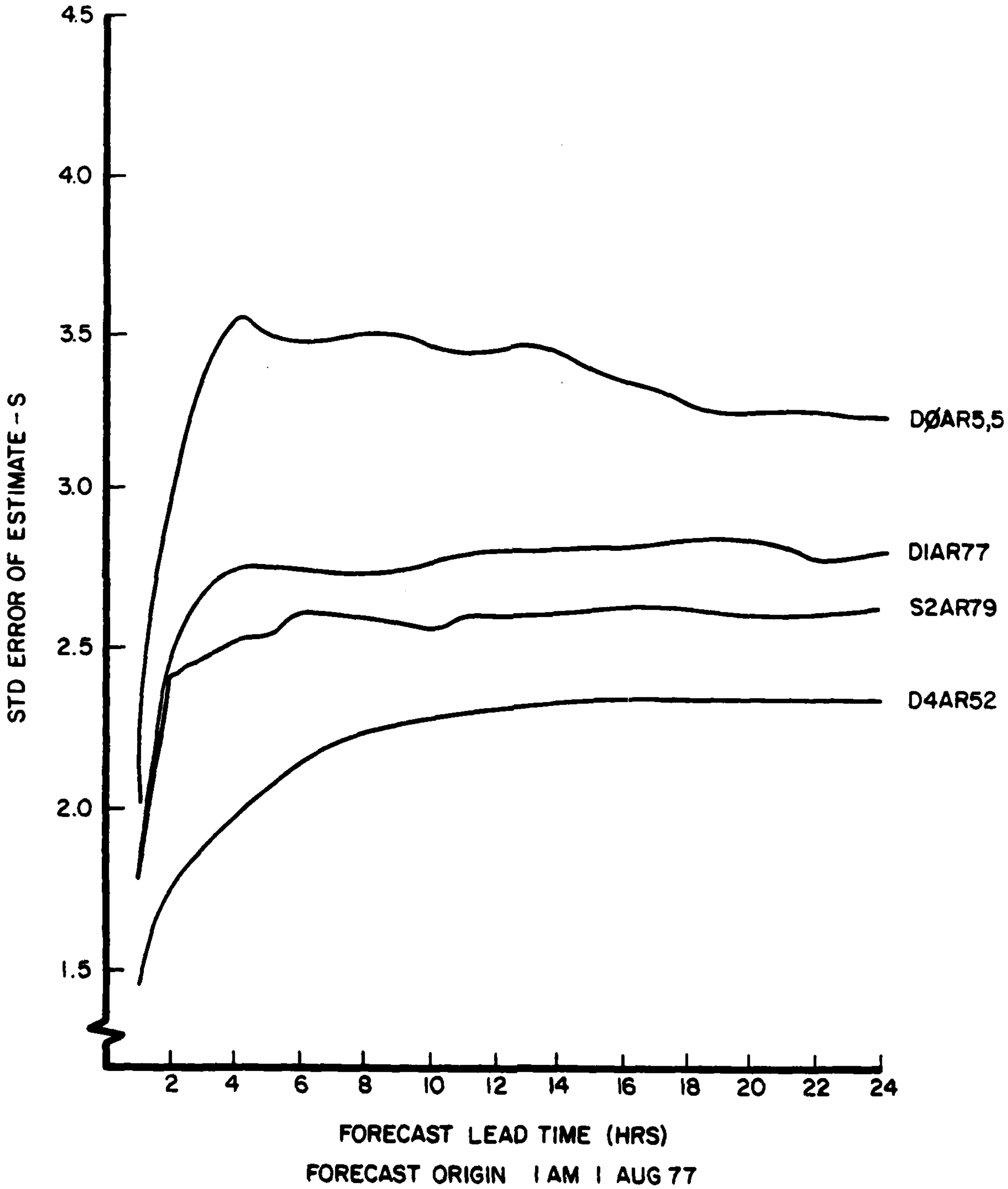


Figure 22. Model error.

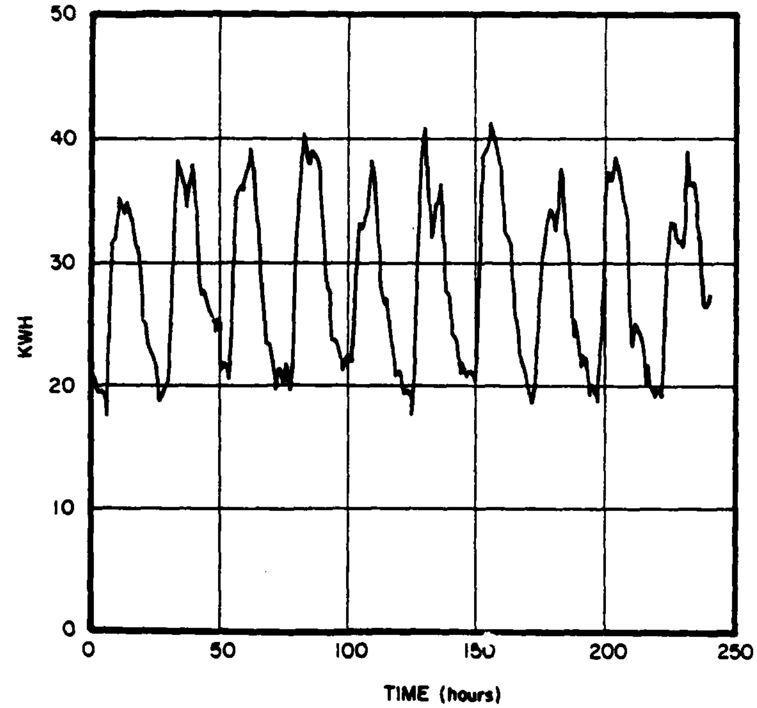


Figure 23. Actual future energy consumption.

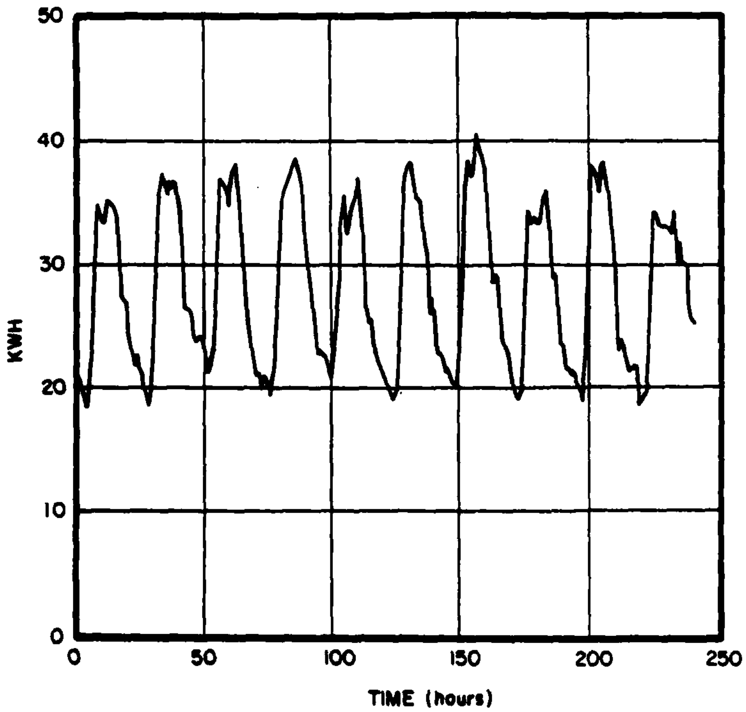


Figure 24. Model prediction of future energy consumption.

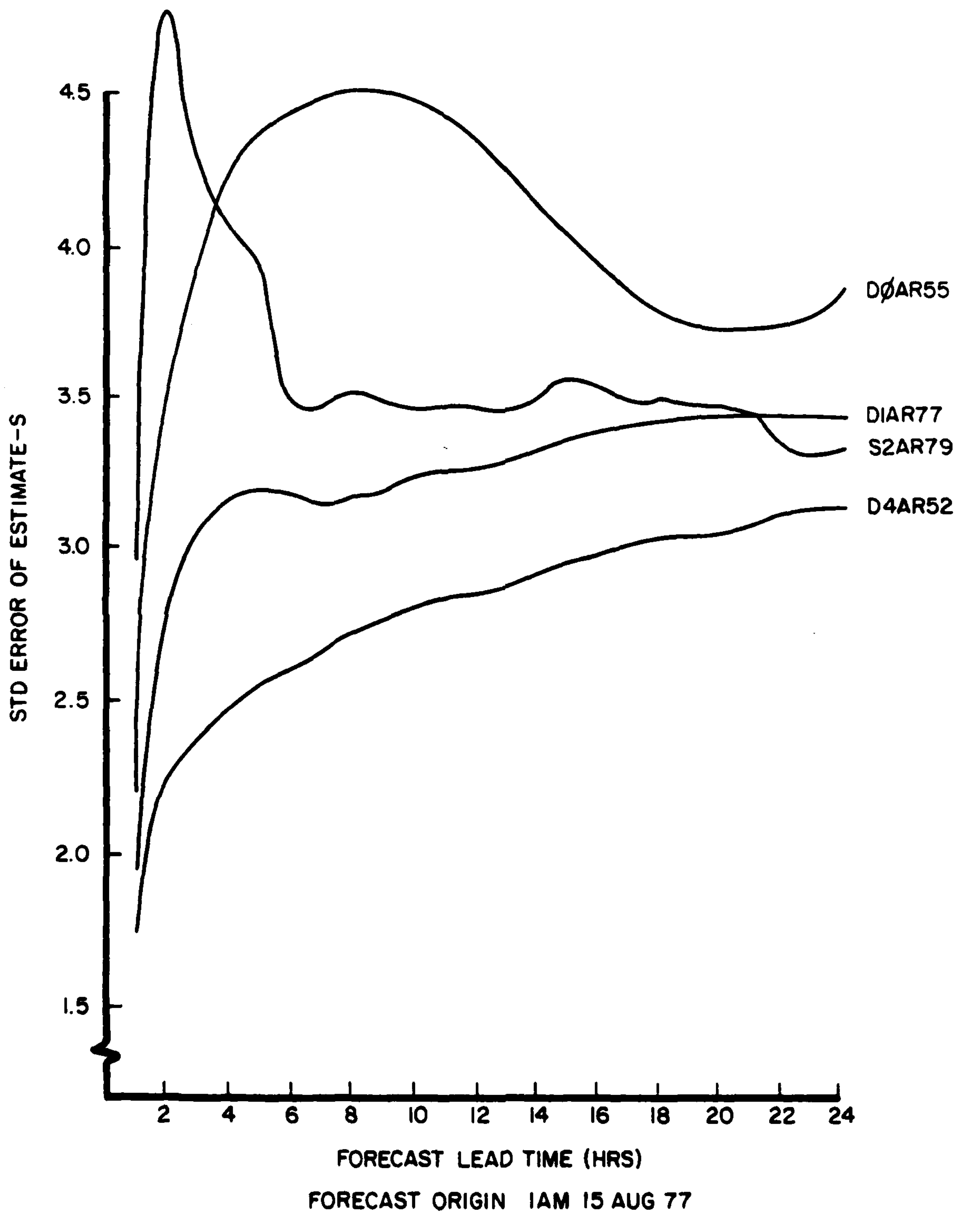


Figure 25. Model Forecast Error.

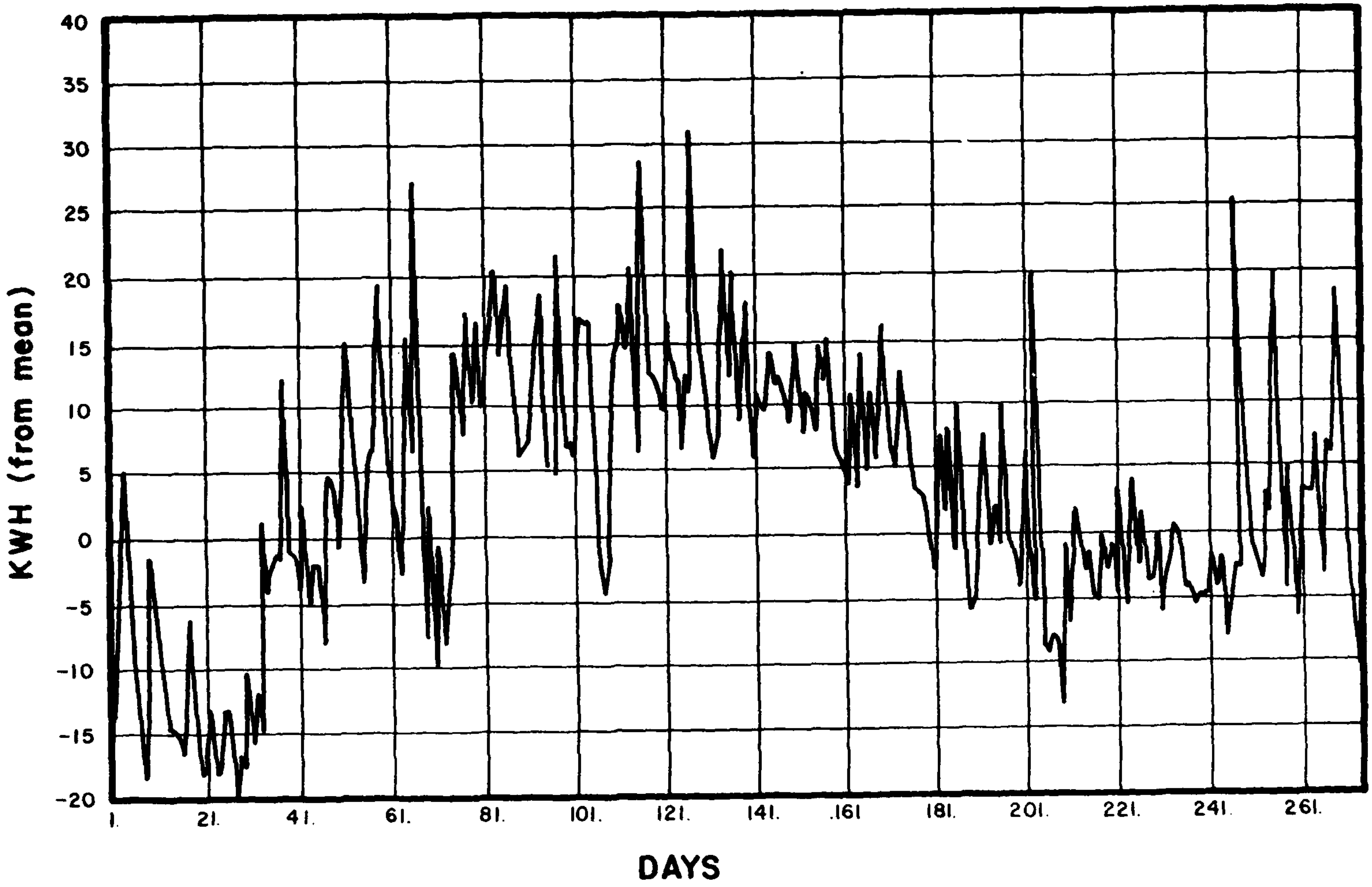


Figure 26. Family housing unit electrical consumption for 1977–1978 heating season.

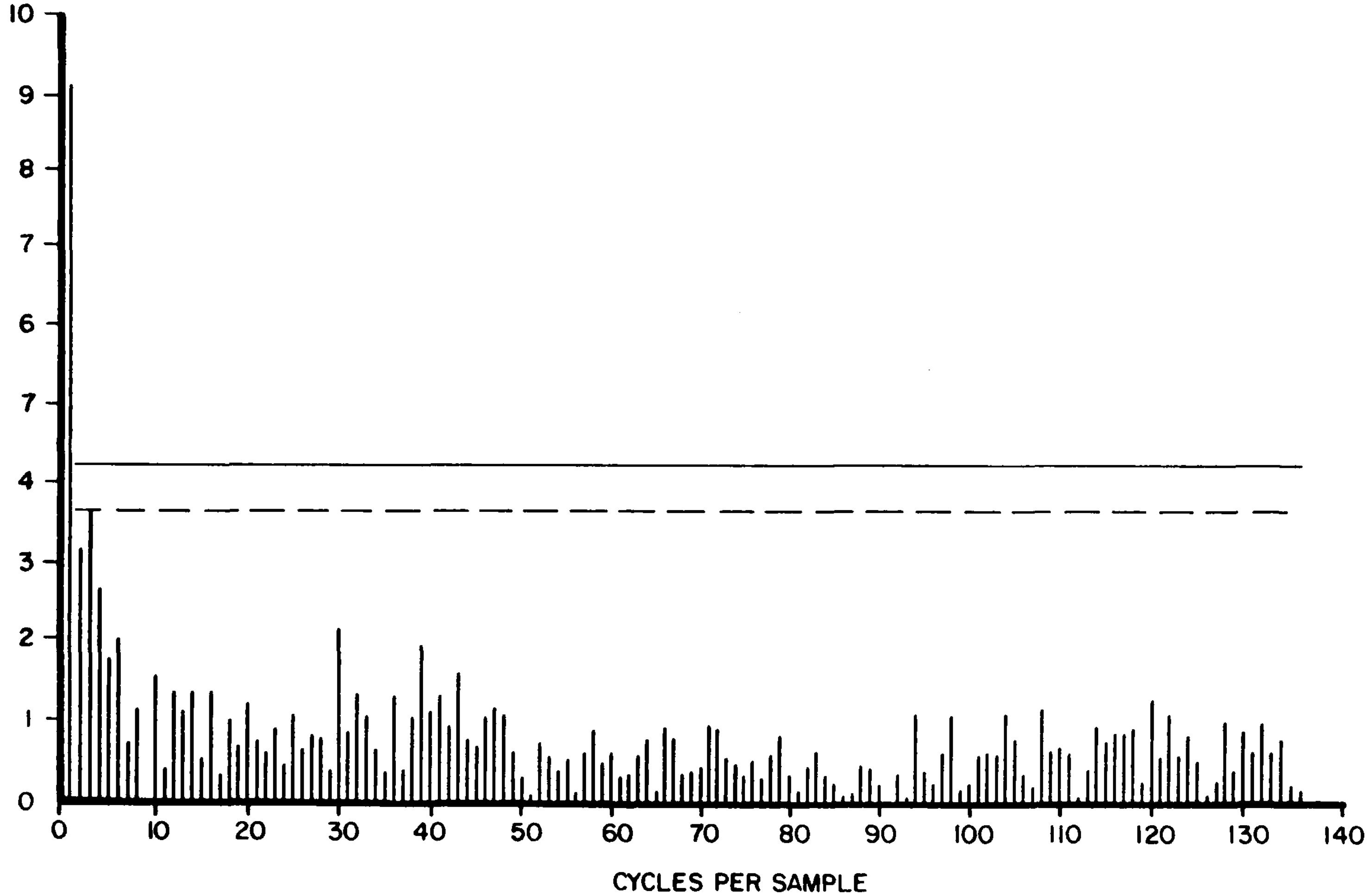


Figure 27. Results of Fourier analysis.

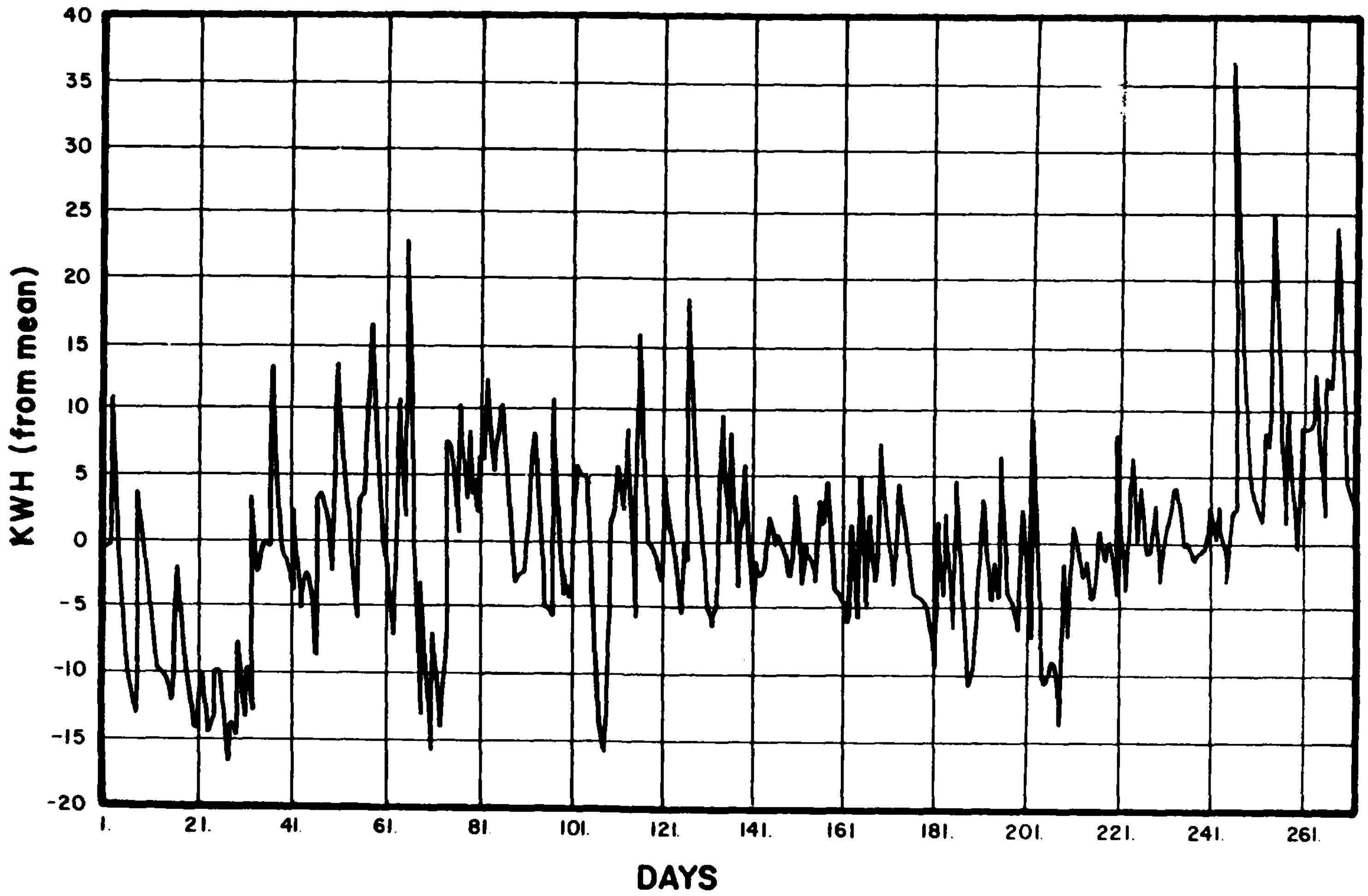


Figure 28. Family housing data with periodicity removed.

APPENDIX A: METHOD FOR CALCULATING N

For an ARMA (n,m) model:

$$S_x^2 =$$

$$\mathrm{Var}\,(X) = \frac{\sigma_a^2}{N}\left[\frac{(1 - \sum_{j=1}^{m} \Theta_j)}{(1 - \sum_{i=1}^{n} \Phi_i)}\right]^2$$

where

$$\sigma_a^2 = \frac{\text{Residual Sum Sq}}{N - (n + m + 1)}$$

N = Sample size

Θ_j = Theta parameter of ARMA model

Φ_i = Phi parameter of ARMA model

DDS gives σ_x^2; $\sigma_x^2 = \frac{S_x^2}{N} \sigma_x = \frac{S_x}{\sqrt{N}}$

$$Z = \frac{x - \mu}{\sigma_x} = (x - \mu)/S_v\sqrt{N}$$

$$Z = (x - \mu)(\overline{N})/S_x$$

$$\sqrt{N} = \frac{Z\,S_x^2}{(X - \mu)}$$

$$N = \frac{Z^2 S_x^2}{(X - \mu)^2}$$

Note: $Z = 1.96$ for a 95 percent confidence interval.

CERL DISTRIBUTION

Chief of Engineers
ATTN: Tech Monitor
ATTN: DAEN-ASI-L (2)
ATTN: DAEN-CCP
ATTN: DAEN-CW
ATTN: DAEN-CWE
ATTN: DAEN-CWR-W
ATTN: DAEN-CWO
ATTN: DAEN-CWP
ATTN: DAEN-EC
ATTN: DAEN-ECC
ATTN: DAEN-ECE
ATTN: DAEN-ZCF
ATTN: DAEN-ECB
ATTN: DAEN-RD
ATTN: DAEN-RDC
ATTN: DAEN-RDM
ATTN: DAEN-RM
ATTN: DAEN-ZCZ
ATTN: DAEN-ZCE
ATTN: DAEN-ZCI
ATTN: DAEN-ZCM

FESA, ATTN: Library 22060

FESA, ATTN: DET III 79906

US Army Engineer Districts
ATTN: Library
Alaska 99501
Al Batin 09616
Albuquerque 87103
Baltimore 21203
Buffalo 14207
Charleston 29402
Chicago 60604
Detroit 48231
Far East 96301
Fort Worth 76102
Galveston 77550
Huntington 25721
Jacksonville 32232
Japan 96343
Kansas City 64106
Little Rock 72203
Los Angeles 90053
Louisville 40201
Memphis 38103
Mobile 36628
Nashville 37202
New England 02154
New Orleans 70160
New York 10007
Norfolk 23510
Omaha 68102
Philadelphia 19106
Pittsburgh 15222
Portland 97208
Riyadh 09038
Rock Island 61201
Sacramento 95814
San Francisco 94105
Savannah 31402
Seattle 98124
St. Louis 63101
St. Paul 55101
Tulsa 74102
Vicksburg 39180
Walla Walla 99362
Wilmington 28401

US Army Engineer Divisions
ATTN: Library
Europe 09757
Huntsville 35807
Lower Mississippi Valley 39180
Middle East 09038
Middle East (Rear) 22601
Missouri River 68101
North Atlantic 10007
North Central 60605
North Pacific 97208
Ohio River 45201
Pacific Ocean 96858
South Atlantic 30303
South Pacific 94111
Southwestern 75202

US Army Europe
HQ, 7th Army Training Command 09114
ATTN: AETTG-DEH (5)
HQ, 7th Army ODCS/Engr. 09403
ATTN: AEAEN-EH (4)
V. Corps 09079
ATTN: AETVDEH (5)
VII. Corps 09154
ATTN: AETSDEH (5)
21st Support Command 09325
ATTN: AEREH (5)
Berlin 09742
ATTN: AEBA-EN (2)
Southern European Task Force 09168
ATTN: AESE-ENG (3)
Installation Support Activity 09403
ATTN: AEUES-RP

8th USA, Korea
ATTN: EAFE (8) 96301
ATTN: EAFE-Y 96358
ATTN: EAFE-ID 96224
ATTN: EAFE-4M 96208

8th USA, Korea
ATTN: EAFE-H 96271
ATTN: EAFE-P 96259
ATTN: EAFE-T 96212

ROK/US Combined Forces Command 96301
ATTN: EUSA-HHC-CFC/Engr

USA Japan (USARJ)
Ch, FE Div, AJEN-FE 96343
Fac Engr (Honshu) 96343
Fac Engr (Okinawa) 96331

Rocky Mt. Area 80903

Area Engineer, AEDC-Area Office
Arnold Air Force Station, TN 37389

Western Area Office, CE
Vanderberg AFB, CA 93437

416th Engineer Command 60623
ATTN: Facilities Engineer

US Military Academy 10996
ATTN: Facilities Engineer
ATTN: Dept of Geography & Computer Science
ATTN: DSCPER/MAEN-A

Engr. Studies Center 20315
ATTN: Library

AMMRC, ATTN: DRXMR-WE 02172

USA ARRCOM 61299
ATTN: DRCIS-RI-I
ATTN: DRSAR-IS

DARCOM - Dir., Inst., & Svcs.
ATTN: Facilities Engineer
ARRADCOM 07801
Aberdeen Proving Ground 21005
Army Matls. and Mechanics Res. Ctr.
Corpus Christi Army Depot 78419
Harry Diamond Laboratories 20783
Dugway Proving Ground 84022
Jefferson Proving Ground 47250
Fort Monmouth 07703
Letterkenny Army Depot 17201
Natick R&D Ctr. 01760
New Cumberland Army Depot 17070
Pueblo Army Depot 81001
Red River Army Depot 75501
Redstone Arsenal 35809
Rock Island Arsenal 61299
Savanna Army Depot 61074
Sharpe Army Depot 95331
Seneca Army Depot 14541
Tobyhanna Army Depot 18466
Tooele Army Depot 84074
Watervliet Arsenal 12189
Yuma Proving Ground 85364
White Sands Missile Range 88002

DLA ATTN: DLA-WI 22314

FORSCOM
FORSCOM Engineer, ATTN: AFEN-FE
ATTN: Facilities Engineer
Fort Buchanan 00934
Fort Bragg 28307
Fort Campbell 42223
Fort Carson 80913
Fort Devens 01433
Fort Drum 13601
Fort Hood 76544
Fort Indiantown Gap 17003
Fort Irwin 92311
Fort Sam Houston 78234
Fort Lewis 98433
Fort McCoy 54656
Fort McPherson 30330
Fort George G. Meade 20755
Fort Ord 93941
Fort Polk 71459
Fort Richardson 99505
Fort Riley 66442
Presidio of San Francisco 94129
Fort Sheridan 60037
Fort Stewart 31313
Fort Wainwright 99703
Vancouver Bks. 98660

HSC
ATTN: HSLO-F 78234
ATTN: Facilities Engineer
Fitzsimons AMC 80240
Walter Reed AMC 20012

INSCOM - Ch, Instl. Div.
ATTN: Facilities Engineer
Arlington Hall Station (2) 22212
Vint Hill Farms Station 22186

MDW
ATTN: Facilities Engineer
Cameron Station 22314
Fort Lesley J. McNair 20319
Fort Myer 22211

MTMC
ATTN: MTMC-SA 20315
ATTN: Facilities Engineer
Oakland Army Base 94626
Bayonne MOT 07002
Sunny Point MOT 28461

NARADCOM, ATTN: DRDNA-F 071160

TARCOM, Fac. Div. 48090

TRADOC
HQ, TRADOC, ATTN: ATEN-FE
ATTN: Facilities Engineer
Fort Belvoir 22060
Fort Benning 31905
Fort Bliss 79916
Carlisle Barracks 17013
Fort Chaffee 72902
Fort Dix 08640
Fort Eustis 23604
Fort Gordon 30905
Fort Hamilton 11252
Fort Benjamin Harrison 46216
Fort Jackson 29207
Fort Knox 40121
Fort Leavenworth 66027
Fort Lee 23801
Fort McClellan 36205
Fort Monroe 23651
Fort Rucker 36362
Fort Sill 73503
Fort Leonard Wood 65473

TSARCOM, ATTN: STSAS-F 63120

USACC
ATTN: Facilities Engineer
Fort Huachuca 85613 (2)
Fort Ritchie 21719

WESTCOM
ATTN: Facilities Engineer
Fort Shafter 96858
ATTN: APEN-IM

SHAPE 09055
ATTN: Survivability Section, CCB-OPS
Infrastructure Branch, LANDA

HQ USEUCOM 09128
ATTN: ECJ 4/7-LOE

Fort Belvoir, VA 22060
ATTN: ATZA-DTE-EM
ATTN: ATZA-DTE-SW
ATTN: ATZA-FE
ATTN: Engr. Library
ATTN: Canadian Liaison Office (2)
ATTN: IWR Library

Cold Regions Research Engineering Lab 03755
ATTN: Library

ETL, ATTN: Library 22060

Waterways Experiment Station 39180
ATTN: Library

HQ, XVIII Airborne Corps and Ft. Bragg 28307
ATTN: AFZA-FE-EE

Chanute AFB, IL 61868
3345 CES/DE, Stop 27

Norton AFB 92409
ATTN: AFRCE-MX/DEE

Tyndall AFB, FL 32403
AFESC/Engineering & Service Lab

NAFEC
ATTN: RDT&E Liaison Office
Atlantic Division 23511
Chesapeake Division 20374
Southern Division 29411
Pacific Division 96860
Northern Division 19112
Western Division 64066
ATTN: Sr. Tech. FAC-03T 22332
ATTN: Asst. CDR R&D, FAC-03 22332

NCEL 93041
ATTN: Library (Code L08A)

Defense Technical Info. Center 22314
ATTN: DDA (12)

Engineering Societies Library 10017
New York, NY

National Guard Bureau 20310
Installation Division

US Government Printing Office 22304
Receiving Section/Depository Copies (2)

US Army Env. Hygiene Agency
ATTN: HSHB-E 21010

ESD Team Distribution

HQDA (DALO-TSE-F) (3) 20310

US Army Engineer Districts (39)
ATTN: Chief, Engineer Division

US Army Engineer Divisions (15)
ATTN: Chief, Engineer Division

Army-Air Force Exchange Service 75222
ATTN: Chief, Engineering Div

Alexandria, VA 22314
ATTN: DLA-W

USA ARRADCOM 07801
ATTN: DRDAR-LCM-SP

USA DARCOM
ATTN: DRCIS 22333

Fort Belvoir, VA 22060
ATTN: DRDME-G
ATTN: FESA-TSD

Fort Leavenworth, KS 66027
ATTN: ATZLCA-SA

Naval Civil Engineering Laboratory 93043
ATTN: Code L03AE
ATTN: Code L60

Naval Facilities Engineering Command 22332
ATTN: Code 032E
ATTN: Code 1023
ATTN: Code 11130
ATTN: Code 044

USAF
ATTN: SAFMII 20330

Andrews AFB, WASH DC 20331
ATTN: AFSC-DEE

Patrick AFB, FL 32925
ATTN: XRQ

Tyndall AFB, FL 32403
ATTN: RD

Wright-Patterson AFB, OH 45433
ATTN: POE
ATTN: PMD

Assistant Sec for Conservation & Solar Energy 20314
Assistant Sec for Resource Applications 20314
OCNO (Logistics) 20301
Director, Bldg Technology & Safety Div 20410
Director, Center for Building Technology 20234
Energy Research and Development Foundation 30037
ODAS (EE&S) 20301
ODAS (I&H) 20301
GSA 20405
Public Building Service 20405

Department of Energy 30037
Oak Ridge, TN 37830

Sliwinski, Ben J.
Analysis of facilities energy use patterns / by Ben J. Sliwinski, Elizabeth Elischer. -- Champaign, Ill : Construction Engineering Research Laboratory ; available from NTIS, 1983.
68 p. (Technical report / Construction Engineering Research Laboratory ; E-186)

1. Buildings -- energy consumption. I. Elischer, Elizabeth. I. Title. III. Series: Technical report (Construction Engineering Research Laboratory) ; E-186.

END

FILMED

9-83

DTIC